THE

GEOLOGICAL OBSERVER.

THE

GEOLOGICAL

OBSERVER.

BY

SIR HENRY T. DE LA BECHE, C.B., F.R.S., &c.

DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEY
OF THE UNITED KINGDOM.

SECOND EDITION, REVISED.

LONDON:
LONGMAN, BROWN, GREEN, AND LONGMANS.
1853.

LONDON: PRINTED BY W. CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

PREFACE.

It has been well remarked by Humboldt* that to behold is not necessarily to observe, that is, to compare and combine. The history of Geology, like that of all sciences depending for their effective advance on experiment or correct observation, amply proves the truth of this statement. We are not required to look far back to be fully aware of the many brilliant hypotheses which have given way before the advance of correct research. It was not that these brilliant hypotheses were intended as substitutes for sound geological knowledge, based on correct data, or that those who formed them were not as capable as any who may in after-times succeed in still farther systematically embodying the accumulated data of such times, but merely that correct observations were not then sufficiently abundant, and that powerful, and, sometimes, impatient minds supplied their place with conceptions more captivating than well founded. It is obvious that with a hundred well-established facts more can be accomplished than with ten, the deductions from which, however apparently correct, may even be fallacious as respects those derived from the consideration of the greater number. Let it not, nevertheless, be hastily concluded that the views which have passed away have not materially advanced geology, as those of a similar character have aided the progress of other sciences. Without them, though a few may have been impediments for the time, many a subject would have longer remained disregarded by its zealous investigator. Even the controversies which have from time to time appeared, many from differences of opinion arising the more readily as the subject was

* Kosmos.

less perfectly understood, gave a certain impulse to progress which the commencement of many inquiries so often demands.

The following work was undertaken in the hope that the experience of many years might assist, and, perhaps, abridge the labours of those who may be desirous of entering upon the study of geology, and especially in the field. Its object is, to afford a general view of the chief points of that science, such as existing observations would lead us to infer were established; to show how the correctness of such observations may be tested; and to sketch the directions in which they may apparently be extended. Having been, to a certain extent, founded upon a little treatise, entitled "How to Observe in Geology," long since out of print, a somewhat similar name has been retained for the present volume.

H. T. De la Beche.

CONTENTS.

Page

CHAPTER XXXV.

CHAPTER XXXVI.

CHAPTER XXXVII.

APPENDIX

INTRODUCTION.

Observations have now been sufficiently extended and multiplied to show that, during a long lapse of time, the surface of our planet has been undergoing modifications and changes. Of these the most marked have been produced by the uprise of mineral matter in a molten state from beneath that surface; by the wearing away and removal to other localities of this matter, either in its first state, after cooling, or in some secondary condition, by atmospheric influences and waters variously distributed for the time being; by the preservation of the remains of animal and vegetable life during at least a portion of this lapse of time amid deposits accumulated, for the most part, in horizontal layers beneath waters, and by the unquiet state of the earth's surface itself, from which, while considerable areas have been at different times raised slowly above, and depressed beneath the level of the ocean, whole masses of mineral matter of various kinds have occasionally been squeezed, bent, and plicated, sometimes ridged up into ranges of mountains.

To enable the geologist systematically to proceed with his researches, it became as needful for him as for other cultivators of science to have the power of classifying his observations. Of the various classifications proposed or modified at different times to satisfy the amount of knowledge of those times, it would be out of place here to make mention, further than to remark that at present a more mixed classification is often employed than seems desirable. For example, it is not unusual for the term *tertiary*, or *tertiaries*, to be applied to all accumulations posterior to the chalk of western Europe, while the other terms of secondary and primary or primitive, to which it has reference, are scarcely or seldom mentioned. We have, again, a mixed nomenclature for the groups of deposits, or the deposits themselves, for which it has been thought desirable to

find distinctive names. While some groups are referred to localities, such as Cambrian, Silurian, Jurassic, and the like; others are named after some circumstance supposed characteristic, such as carboniferous, from containing the great coal deposits of Europe and North America; or oolitic, from many of the limestones in it being oolitic, that is, resembling the roe of a fish, being composed of numerous small rounded grains.

It has been often considered that names derived from localities, where certain deposits have been taken as types, are preferable to those pointing to any mineral structure, inasmuch, as not only can the geologist readily make himself familiar with the kind of accumulations intended to be represented by the names, by visiting and studying the localities whence they are taken, but as also particular mineral structures having been repeated as often as the conditions for them arose, they form no guide for determining the relative age of rocks, whatever may have been the impression when names of that kind were given, and geological science less advanced than at present. The two structural names mentioned are thus liable to objection, carboniferous deposits extending from an earlier period than that supposed to be represented by the term, and up to the higher accumulations above the cretaceous series inclusive, and the oolitic character reaching from limestones amid the earlier fossiliferous rocks to the present day.* The mixed character of the present geological nomenclature arises, no doubt, from the manner in which, from time to time, various geologists have directed attention to different rocks or accumulations of them, those names having generally remained which have been found convenient and sufficient, up to the present time, for the purposes for which they have been employed.

The igneous products being those from which the chief part, if not the whole, of the detrital, and even chemical deposits have been directly or indirectly derived, it would appear desirable to consider them in the first place. Whatever the views entertained of the fluid condition of our planet, whence its form has resulted, such fluid condition produced by heat sufficient to keep all its com-

* One of the limestones of the lower Silurian series in North Wales, the Rhiwlas, near Bala, is oolitic.

ponent parts in that state, the present condition of the earth's surface in dispersed localities shows an abundance of points through which igneous products are now ejected, and the more extended the observation, the more certain does the inference appear correct, that the like has happened from the earliest times; at least since the seas were tenanted by life. It has also been ascertained that molten matter has risen from beneath in more massive forms, and in a manner with which we are not familiar, as now occurring, though such molten masses may, indeed, be formed at depths in the earth's crust, whence only future geological changes could bring them above the level of the sea. At all events, this massive form of intrusion is found amid comparatively recent geological accumulations, as well as among those of the most ancient date.

The mode of occurrence of the igneous rocks, which will be found treated of in its place in the following pages, would seem to point to their classification according to their chemical and mineralogical characters, so that any resemblance or difference that may exist between them, may be traced through the lapse of geological time, the relative dates of their appearance being obtained by means of the accumulations with which they may be associated, and to which relative geological dates can be assigned. Having entered upon these characters in the sequel, the following sketch of the more prominent of the igneous rocks may here suffice:—

Granitic Rocks.—Those composed of a granular mixture of quartz, felspar (whether orthoclase, albite, or labradorite), and mica, with, occasionally, the addition of schorl and some other minerals. As the aspect of these rocks varies considerably according to original chemical composition or the mode of cooling, a great variety of appearances are assumed, to which names have been assigned. It thus becomes desirable that these characters should be given whenever it can be accomplished, and that the mere term *granitic* be accompanied by mineralogical detail, and by a statement of the chemical composition, so that correct data may be collected for a proper appreciation of the real differences and resemblances of the rocks commonly thus named.

Felspathic Rocks.—The separation of these from the foregoing may often be regarded as somewhat imaginary, as indeed is the case with definite classifications of the great bulk of the igneous rocks, passing, as they sometimes do, into each other in masses of no very extraordinary volume. The variety known as compact felspar is most frequently a compound of the

elements of some felspar, with a surplusage of silicic acid beyond that required for the silicates of that mineral, so that when opportunities have occurred for crystallization of the parts, the result has been a compound of felspar and quartz, or a *pegmatite*, as it has been sometimes termed, in that case a modification of the granitic rocks when the same minerals may alone constitute a portion of a general mass. The *trachytes* of active volcanos and those termed extinct, and of comparatively recent geological date, may represent the more pure felspathic rocks, when wholly formed of felspars, though it would appear that similar rocks are also found amid the igneous products of very ancient geological periods. Felspathic matter, that is, the various component substances in proportions which would form minerals of the felspar family (allowing for that substitution of one substance for another, termed *isomorphism*), if crystallized, should at least constitute the great bulk of these rocks, whatever others may be entangled among them.

Hornblendic Rocks.—These, including among them the rocks in which augite is substituted for hornblende, form a somewhat natural division, so far as the prevalence of these minerals may be sufficient to give a character to the mass of an igneous rock, inasmuch as silicate of lime is a marked ingredient, in addition to the silicate of magnesia, another essential substance, and protoxide of iron, generally present, sometimes replacing much of the lime and magnesia. In this division, therefore, are included the dolerites and basalts of active and extinct volcanic products, and the greenstones, generally of more ancient date. In dolerites, silicate of lime is also present in the labradorite, when that member of the felspar family is mingled with the augite of that rock. Taken as a whole, the hornblendic or augitic rocks are compounds of those minerals and some member of the felspar family, there being sometimes an excess of silica beyond the amount required for the various silicates in the hornblende or augite, and felspar; this excess, then, as it were, thrust aside as quartz.

Serpentinous Rocks.—To a certain extent these also appear a somewhat natural group of igneous products, especially when viewed with reference to a peculiar aspect, and to the presence of silicate of magnesia (constituting the bulk of the rock) and combined water. In the sequel we have endeavoured to show the correspondence between the varieties of serpentine, considered the most pure, and olivine, a common mineral in certain molten products of active and extinct volcanos. The rocks of this division vary, however, somewhat materially in their constituent substances, and in the proportions of them. Taking *bronzite* to be the mineral usually named diallage, it would appear little else than the silicate of magnesia of the matter of the purer serpentine mingled with a minor proportion of protoxide of iron, and a little alumina, crystallized, a small quantity of water also ...al now chiefly named *diallage* contains

sufficient lime in addition to make it essentially a silicate of lime and magnesia, with also a marked quantity of oxide of iron. In the compound, sometimes largely crystallized, termed *diallage rock* (*gabbro*), and not unfrequently associated with serpentine, the so-termed diallage has to be carefully examined. In all these rocks, whatever their variations, magnesia is a marked ingredient.

Porphyritic Rocks.—Though, no doubt, various kinds of mineral matter which have been in a molten state may be porphyritic, that is, have some mineral or minerals crystallized out and apart from the mass of the remainder of the rock, it seems nevertheless convenient, for the present, to notice these rocks as a group. Even amid vitreous matter, from comparatively quick cooling after fusion, definite chemical combinations may be crystallized, and dispersed through such matter. This can be artificially accomplished in our laboratories, and silicate of lime in crystals can be obtained dispersed through ordinary glass. In the arrangement of particles, beyond the vitreous condition, forming the compact and stony state, the porphyritic character is not rare among rocks; crystals, such as those of felspar, being dispersed amid a base of compact mineral matter. When the latter is chiefly felspathic, the rock is usually known as *felspar porphyry*. In like manner crystals of other minerals are also thus dispersed amid a similar base, such as those of quartz and mica. The base or general mass of the rock is occasionally granular, such as a compound of felspar and hornblende, constituting greenstone, with dispersed crystals of felspar or hornblende, such base having thus advanced to a state of confused crystallization. These are usually termed *greenstone porphyries*. In like manner certain granites become porphyritic, from separate crystals of felspar being scattered among the general compound, confusedly crystallized, and the rock is then called a *porphyritic granite*. Even serpentines become in a manner porphyritic when crystals of bronzite or diallage are dispersed through a base of that rock. The apparent conditions are, that the chemical composition and the mode of cooling of the general mass are such that certain constituent substances can combine and form separate and definite crystallized bodies, the remainder of the rock either not attaining the state when definite mineral compounds can be formed, or only doing so after the production of the first-formed minerals, and then in a confused manner, not interfering with the forms of the crystals first produced.

With regard to the mineral accumulations derived either directly or indirectly from the igneous rocks, and spread over areas of varied extent and form, by means of water, there is a large mass, more or less characterized by the presence among it of the remains of animals and plants which have existed at different periods, and so perishing, that portions of them, commonly only the harder

parts, have been entombed in the mineral accumulations of such different times.

Observation has shown that these accumulations have succeeded one another, as the various detrital deposits in lakes and seas now succeed those which have preceded them, so that, when the ancient sea or lake bottoms, which, elevated into the atmosphere, now constitute so large a portion of dry land, can be studied in cliffs or other natural sections, or by artificial cuttings or perforations, their manner of succession can be ascertained. The more investigations have advanced, the more does it appear that these organic-remain bearing, or *fossiliferous rocks*, as they have been termed, have been deposited and arranged as similar accumulations now are in rivers, estuaries, lakes, and seas. Hence, the geologist, in endeavouring to ascertain the range of such fossiliferous deposits at any given time upon the earth's surface, has to consider the relative amount and position of the land and waters of that time, with all their modifying influences, as also the various conditions under which the life of the period may have been distributed, and its remains entombed amid the detrital and chemical deposits of the day. In fact, he has, from all the evidence he can collect, to suppose himself studying the state of the earth's surface, at such given time, as well with respect to its physical condition as to the existence and distribution of life upon it.

Viewing the fossiliferous rocks in this manner, it may be that some of those divisions among them, which it has been found convenient to make for their more ready description, and the tracing of certain states of a sea-bottom over minor areas, have been too minute, regarded as divisions applicable to the surface of the earth generally, since it is not to be supposed that particular mud or sand banks, however considerable locally, were more likely to have been formerly continued, even at intervals, over the earth's surface than they now are. At the same time such minor divisions, showing the constancy or modification of conditions, as the case may be, over the minor areas, are important, inasmuch as it is by a correct appreciation of this detail and the careful consideration of how much may be regarded in that light and how much as more general, that we learn the true value of the latter,

and the restrictions which should be placed upon our views derived from the former.

Assuming the general condition of the earth's surface during the accumulation of the varied deposits in which the remains of animal and vegetable life have been entombed, to have been formerly much as at present, regarding the subject on the large scale, and without reference, for the moment, to the variable distribution of land and water, or to whether the heat in the earth itself may or may not, in remote times, have had a greater influence on the life of those times than at present, the sea would appear to have been the chief receptacle of the various mineral accumulations of all periods, so that classifications of the fossiliferous rocks, founded on a succession of deposits in it, would probably be alike the most useful and natural. The manner in which marine invertebrate animals now live, and the mode in which the remains of similar animals occur amid the fossiliferous rocks, are such, that this division of life seems now very generally admitted as the most appropriate on which to base classifications founded on the distribution of animals, the remains of which are discovered entombed in rocks. We must refer to succeeding pages for notices of the manner in which the remains of life are now preserved in mineral deposits, and for certain points connected with the occurrence of such remains in the accumulations of various geological dates which it appears desirable to bear in mind while studying the fossiliferous rocks. It will be sufficient here to mention that, after first duly ascertaining the actual relative superposition of the various mineral accumulations themselves for evidence of their real succession, and examining the remains of animal and vegetable life which have been found in them, it has been inferred that certain minor and major divisions may be effected in the general mass which shall represent the kinds of sea-bottoms marking given and succeeding geological times. Without, in the least, doubting that very great modification may be found needed in classifications based upon the examinations of even considerable areas, when an effective classification, representing the main facts connected with the accumulation and spread of fossiliferous rocks over large portions of the earth's surface, may be necessary, it still becomes

desirable to have that which may satisfy the requirements for the time being. The following sketch, therefore, of the general divisions at present considered desirable for the area of Western Europe, and supposed, in part at least, to be found also convenient for the mode of viewing the fossiliferous deposits in many other parts of the world, may be useful, especially as respects the major divisions.

Stratified and Fossiliferous Rocks.

I. Tertiary, or Cainozoic.
II. Secondary, or Mesozoic.
III. Primary, or Palæozoic.

I. Tertiary, or Cainozoic.

A. Upper	*a* Mineral accumulations of the present time. *b* Pleistocene. *c* Pleiocene.
B. Middle	*a* Miocene.
C. Lower	*a* Eocene.

II. Secondary, or Mesozoic.

A. Cretaceous Group . .	*a* Chalk of Maestricht and Denmark. *b* Ordinary chalk, with and without flints. *c* Upper Green Sand. *d* Gault. *e* Shanklin Sands, Vecten, Neocomian, or Lower Green Sand.	
B. Marine equivalents of .	*a* Wealden clay . . *b* Hastings sands . *c* Purbeck series. .	Organic remains in these are of a fluviatile, lacustrine, or estuary character.*
C. Jurassic or Oolitic Group	*a* Portland oolite or limestone.† *b* Portland sands. *c* Kimmeridge clay. *d* Coral rag, and its accompanying grits. *e* Oxford clay, with Kelloways rock. *f* Cornbrash. *g* Forest marble, and Bath oolite. *h* Fuller's earth, clay, and limestone. *i* Inferior oolite, and its sands. *k* Lias, upper and lower, with its intermediate marlstone.	

* The recent researches of Professor Edward Forbes among the Purbeck series have fully illustrated the prudence of not trusting to fresh-water molluscs as characterizing particular divisions in deposits, at least those ranging downwards to that part of the fossiliferous series, he having ascertained that it required most careful critical examination to distinguish the fresh-water shells of that series, as it occurs at Purbeck, from those of certain existing fresh-water molluscs in England and part of Europe.

† The minor divisions of this group have been given with reference to those usually

D. Trias Group* . . .	*a* Variegated marls, Marnes Irisées, Keuper. *b* Muschelkalk.† *c* Red sandstone, Grès Bigarré, Bunter sandstein.

III. Primary, or Palæozoic.

A. Permian Group . . .	*a* Zechstein, Dolomitic or magnesian limestone. *b* Rothe todte liegende, lower new red conglomerate and sandstones, Grès Rouge.
B. Marine equivalents of ‡ .	*a* Coal measures, Terrain Houiller, Stein Kohlen Geberge.
C. Carboniferous limestone Group.	*a* Carboniferous and mountain limestone, with its coal, sandstone, and shale beds in some districts. Calcaire carbonifère, Bergkalk. *b* Carboniferous slates and yellow sandstone.
D. Devonian group . .	*a* Various modifications of the old red sandstone series.
E. Silurian Group . . .	*a* Upper; Ludlow Rocks, Wenlock shale and limestone, Woolhope Limestone. *b* Middle; Caradoc sandstone and conglomerate. *c* Lower; Llandeilo, Bala and Snowdon beds.
F. Cambrian Group . .	*a* Barmouth sandstones, Penrhyn slates, Longmynd rocks, &c. Various rocks subjacent to the Silurian series in Wales and Ireland.

employed in England for the sake of English observers. Many modifications have been shown to be effected in other European countries. Of these divisions those of the Oxford clay and lias would appear much extended.

* The Trias and Permian groups afford an example, as regards the British islands, of a classification taken from organic remains in preference to the mode of occurrence of the rocks themselves, these groups here constituting parts of a general series of deposits with a somewhat marked general character, known as the new red sandstone. Certain general physical conditions were prevalent during the accumulation of these deposits in Great Britain, and certain portions of Western Europe, at the time that a modification in the life of the period was apparently effected in the same area and those adjacent to it on the north and east.

† In the collections lately brought to England by Captain Strachey, Bengal Engineers, after an examination of the Himalaya range, the forms of certain organic remains from the Thibet side of those mountains remind the geologist of those found marking the Muschelkalk of Germany; an interesting circumstance, considering the range of that rock in Europe.

‡ When the great thickness of these deposits in Europe and America is considered, it becomes very desirable to find their marine equivalents, inasmuch as the conditions under which the great mass of these coal measures has been accumulated, as has been noticed in the sequel, could scarcely constitute other than minor parts of those generally prevailing at the time. It is easy to conceive, as has indeed been done, that their marine equivalents might contain either the organic remains usually found in the deposit beneath them in parts of Western Europe, or those found in the group above them, or a mixture of both. In Northern England the alternations of conditions by which coal beds were included in the carboniferous limestone series, did not interrupt those for the existence of a marked kind of marine animal life in the same localities.

Altered or Metamorphic Rocks.

With the classification of detrital and chemical accumulations, effected by the aid of water, and of earlier geological date than those last mentioned (the Cambrian), there are many difficulties. Indeed the limits which may be assigned to the latter, in descending order, are, in the present state of our knowledge, most uncertain. In the district of the Longmynd (Shropshire) the Cambrian group attains a thickness of 26,000 feet, almost entirely composed of detrital deposits. The same group, as exhibited in North Wales, not only presents a considerable depth of similar accumulations, but also shows, by pebbles in its conglomerates (vicinity of Bangor, Llanberis, &c.), that sands were firmly cemented into sandstones, and these ground into shingles, by water action, prior to the production of such conglomerates. These conglomerates, which also contain rounded fragments of hornblendic and felspathic igneous rocks, of a general character similar to those subsequently vomited forth in the same region amid the Silurian deposits, may only constitute portions of a series in the same manner that many other conglomerates are included in groups of rocks bearing given names; in fact, be the beaches of different portions of the time required for the whole deposit; yet they, with the muds, silts, and sands of the period, become important as pointing to causes in action at that time similar to those from which the like accumulations have been effected in after geological periods. Thus, as far as researches have yet gone, we do not arrive at physical conditions differing, as regards the production of detrital mineral accumulations, in any essential manner, that can be determined, from those which have afterwards influenced the accumulation of similar kinds of mud, silt, sand, and gravel, whether now constituting hard consolidated rocks, or found in a state more resembling that in which they were originally formed.

The aid to the classification of rocks, once supposed to be derived from certain of them having a crystalline or semi-crystalline aspect, yet still preserving a general stratified arrangement of parts, various modifications of them bearing distinct names, such as *gneiss*, *mica slate*, and others, is now well known to be unsatisfac-

tory, inasmuch as such rocks have been ascertained to be of different geological dates. Whenever any heated mass of igneous rocks has been thrown into juxtaposition with detrital accumulations of various kinds (mud, silt, sand, or gravel), the conditions under which the latter are then placed become favourable for the modification of their component parts. Various circumstances, heat being regarded only as one of them, then so act that, besides a tendency of similar matter to gather itself together in irregular forms, particles can often so freely move and adjust themselves, that even minerals of distinct characters are formed, rarely, and sometimes not hitherto, discovered amid any other than these modified or altered rocks. As such modifications or alterations would be expected to depend upon the general chemical character and physical structure of the deposits acted upon, these minerals are found to be combinations of the substances which could readily move and unite in a definite manner. Thus, the altered rocks afford such minerals as *andalusite* (especially a silicate of alumina, the base of clays), *chiastolite* (another mineral, in which silicate of alumina is the chief ingredient), *cyanite* (another form in which the same substance is essential), *staurolite* (where silica, alumina, and peroxide of iron are required), and the *garnet*, with all its differences arising from isomorphism, and in which silica may be prominently combined with alumina or iron, magnesia or lime, as the case may be. While minerals of such kinds could be developed in these altered rocks, we should also anticipate that micaceous and siliceous sands or sandstones, as also those in which fragmentary portions of felspar were mingled, and especially when the latter were not decomposed, would be much modified by a free movement of certain substances. We might expect much obliteration of the grains of the sand, a disposal of the silica in planes, either of original deposit or of cleavage, should that have been effected in the rocks acted upon, as also that the micaceous and felspathic portions might be more gathered together in places, and even readjusted in crystals, since we know, as regards the solution of the component matter of such minerals, that in some veins evidently filling fissures, quartz, mica, and felspar are found either alone, or mingled with other minerals in a manner pointing to

their production from solutions, their component parts derived from the adjacent rocks.

The like circumstances acting upon more simple substances, formed into beds of rock, such as limestones, and the combinations of ordinary calcareous matter with carbonate of magnesia in various proportions, would necessarily also produce modification in the arrangement of the component particles, a confused crystalline adjustment of them being effected, such as that seen in statuary marble, when conditions were most favourable. When these bodies were less pure, mingled with detrital matter of the ordinary kinds, the circumstances would be favourable to the development of different mineral substances, such as garnets and others,* amid the general mass. Looking at the varied modes in which detrital and chemical accumulations have been formed, and the different manner in which they can be acted upon by the influences noticed, either on the minor or large scale, the general result could scarcely be otherwise than of the most varied kind. To attempt, therefore, a classification of these modified or altered rocks relatively to geological dates, would be obviously useless.

In considering rocks of this kind it is needful also to bear in mind the general conditions under which beds of detrital or chemical deposits may be modified, or altered from their original state of accumulation, by other conditions than those of the contact or juxtaposition of mineral matter in a state of igneous fusion. Independently of chemical changes effected by the arrangement of the substances in different states of combination, adjusting themselves according to their affinities and the conditions under which they are then placed,† the circumstances which would arise when

* In this manner crystals of quartz have been sometimes produced in beds of statuary marble, as, for example, that of Carrara.

† We find quartz rocks (that is, grains of quartz, accumulated as sands, and firmly cemented together by silica, the separation of the old surfaces of the sand-grains from the siliceous cement sometimes obscure) as the continuation of ordinary beds of quartzose sandstone, the latter sometimes slightly consolidated, and have simply to infer, to account for the facts observed, silica infiltrated so as to consolidate the beds more in certain situations than in others. Such quartz rocks have often been supposed "altered or metamorphic" in the sense used for some of the same general aspect acted upon, with others, by juxtaposed igneous matter which had been in a fused state from heat; whereas they

such beds of rock were deeply buried beneath great accumulations of mineral matter, have to be carefully considered, if the temperature increases in the manner usually inferred as we descend beneath the surface of the earth, even to moderate distances. Huge masses, representing former wide-spread portions of the earth's surface, might thus be placed under conditions similar to those which produce modification and alteration when igneous matter rises from beneath and is forced amid or against detrital and chemical deposits. When again upheaved, as we know great and wide-spread masses of rock have often been during the lapse of geological time, it would be anticipated that similar matter, acted upon in a similar manner, would present like results, and there is much reason to consider that such influences have been the causes of the modification and alteration we sometimes find.

By carefully regarding altered or metamorphic rocks on the large scale, and with reference to all the conditions under which they may be produced, they are found to constitute a mass of mineral matter of much importance, showing us, in their most crystalline readjusted state, the extremes to which such matter may be modified without the mingling of parts inferred when in a state of igneous fusion. Igneous rocks themselves are often modified, their component particles having, as it were, striven to adjust themselves in a perfect manner as in the detrital and chemical deposits. Thus, ordinary greenstone can be sometimes observed to have its component minerals, hornblende and felspar, presenting the aspect of the rock known as *hornblende rock*, and beds of similar matter, either abraded from solid greenstones or vomited forth as ashes, and arranged in beds by the agency of water, to become the rock known as *hornblende slate*. Thus, then, without attempting to classify these modifications and alterations in the arrangement of the component parts of detrital, chemical, and

are merely more firmly cemented and purer quartzose or siliceous modifications of common hard grits, dispersed amid soft marls and shales in so many deposits. Again, the original crystalline accumulations of more chemically-formed beds have to be duly regarded, and separated from the "altered or metamorphic rocks" under notice, as we know that even confused crystalline deposits have been thus produced.

even igneous accumulations, geologically, as regards relative dates, they still, to a certain extent, constitute a class very convenient for investigation, it being always borne in mind that it is desirable only so to regard them, in the present state of our knowledge.

GEOLOGICAL OBSERVER.

CHAPTER I.

DECOMPOSITION OF ROCKS.—FORMATION OF SOILS.—DECOMPOSITION OF GRANITIC ROCKS.—DECOMPOSITION OF SANDSTONES AND LIMESTONES.—INFLUENCE OF STRUCTURE AND ORGANIC REMAINS ON DECOMPOSITION.—DECOMPOSITION OF ROCKS CONTAINING IRON.

As geological knowledge advances, the more evident does it become that we should first ascertain the various modifications and changes which now take place on the surface of the earth, carefully considering their causes, and then proceed to employ this knowledge, so far as it can be made applicable, in explanation of the geological accumulations of prior date. This done, we should proceed to view the facts not thus explained, with reference to the conditions and arrangements of matter which the form of our planet, the known distribution of its heat, the temperature of the surrounding space, and other obvious circumstances, may lead us to infer would be probable during the lapse of geological time.

The geological observer cannot be long engaged in his researches before he will be struck with the tendency of rocks to decompose by the action of atmospheric influences upon them. He will soon perceive that this decomposition is both chemical and mechanical; that certain mineral bodies more readily give way before these influences than others; and that from altered conditions, as regards such influences, the same kinds of rock will more easily decompose in one situation than in another.

It is in consequence of this decomposition that we have soils supporting that growth of vegetation upon which animal life

depends; for soils are but the decomposed parts of more or less consolidated sea or lake bottoms and of igneous accumulations, with the remains of the vegetation which has grown on them, and of the animals which have lived upon the plants. From the varied configuration of surface the decomposed portions of rocks, forming soils, may not always cover those from whence they were derived, for they may and sometimes have been carried, mechanically suspended in water, to various distances, and there deposited, in such a manner as to be mingled with the decomposed portions of other rocks, or wholly cover over the latter. Be this, however, as it may, the decomposed parts of rocks form the base of the soils, affording soluble mineral matter to the plants requiring it, and presenting a physical structure capable of supporting their growth.

The decomposition of rocks, in its various stages, will require much attention, so that the observer may properly classify the facts coming within the range of his researches. Among rocks of igneous origin, such as granites, greenstones, and the like, he will find that the decomposition of felspar is among the chief causes of the disintegration of the igneous masses of which this mineral may form a part. It would be out of place here to enter upon the composition of the various minerals of the felspar family;* it will be sufficient to refer to those portions of them which are soluble, such as the silicates of potash or soda, as the case may be. These silicates, from the action of carbonic acid in the atmosphere, derived from the decay of vegetation, or brought into contact with them by waters containing it in sufficient abundance, are often readily decomposed. The particles once loosened by decomposition, and some of them carried off in solution, rains and changes of temperature, particularly in regions visited by frosts, act mechanically, and the surface of the rock, under favourable conditions, is removed. From a repetition of these causes the rock becomes decomposed to various depths, according to circumstances. In cases where the remaining portions are either too large or so situated as not to be readily carried away, a coating of the disintegrated insoluble part

* The four minerals of this family which chiefly enter into the composition of rocks, are orthoclase, albite, labradorite, and oligoclase, the general chemical composition of which may be regarded as follows:—

	Silica.	Alumina.	Potash.	Soda.	Lime.
Orthoclase	65·4	18	16·6*a*	–	
Albite .	69·3	19·1	–	11·6*b*	–
Labradorite	33·7	29·7	–	4·5	12·1
Oligoclase	63	24·9	–	12·1*c*	–

a. Including a little soda and lime. *b.* In part often replaced by lime or potash. *c.* Commonly, also, containing potash and lime.

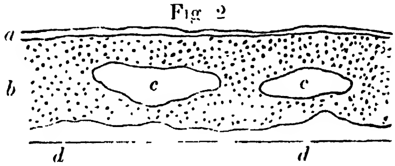
remains, and to a certain extent protects the solid rock beneath from that decomposition which it would otherwise have suffered.

In many granitic regions ample opportunities are afforded of observing the amount of decomposition thus produced; high tors or bosses of rock rising above a surface in a decomposed state

Fig. 1.

(fig. 1), while hard masses, having the fallacious appearance of boulders, rounded by attrition, are sometimes included in the loose decomposed granite, as represented beneath (fig. 2).

Fig. 2

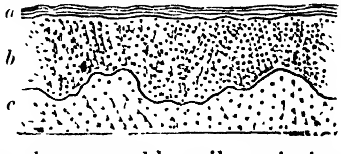


This illustration is taken from part of the road between Okehampton and Moreton Hampstead, Devon. *a* represents the vegetable soil; *b* decomposed granite; *c c* solid rounded masses of undecomposed granite, included in the decomposed part; and *d d* solid granite.

In such a section as this, great care should, however, be taken to ascertain that *c c* are not transported boulders of granite, included in smaller granitic gravel, as sometimes happens with granitic drift, near the sources whence it has been derived. Fortunately in this case the observer would be assisted by the presence of large crystals of felspar disseminated through all parts of the rock, both decomposed and undecomposed, and which are beautifully preserved, remaining uninjured in their forms and in their relative positions throughout the decomposed granite.

In granitic regions, sections such as that beneath (fig. 3), in

Fig. 3.



which *a* represents the vegetable soil, as it is commonly termed,

b the decomposed, and *c* the solid granite, are not unfrequent. Sections of this appearance should, also, be carefully examined, and it be clearly ascertained that the granitic particles at *b* are of the same kind, and in the same general relative positions, as those at *c*, and that there can be no chance of their having been brought into their present position by moving water. The quantity of transported granitic matter around granite districts, as also among them, is sometimes so considerable that a superficial deposit of granitic particles, covering a very different kind of rock, may, without due care, be readily mistaken for a mass of decomposed granite. In the same way the remains of the rock of one part of a granitic region may be removed and cover the rock of another portion.

Among those igneous rocks in which hornblende* forms a marked component part, it sometimes happens that this mineral is also disintegrated.

In the decomposition of the igneous rocks chiefly composed of felspar and hornblende, when the former mineral prevails, the surface of these rocks has usually a white aspect, the soluble silicates of soda or potash, as the case may be, being removed, and a crust, principally formed of silicate of alumina remaining. Where hornblende much prevails, a brownish and reddish surface is common, the protoxide of iron of that mineral having been converted into a peroxide.

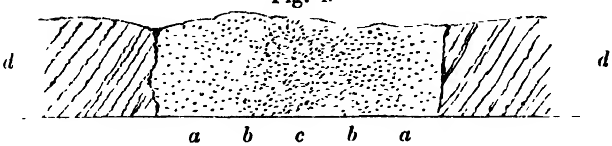
Rocks in which the felspar and hornblende have both been decomposed, are in some situations thickly coated with a loose covering. The variable manner in which a mass of igneous rock that has been placed under equal atmospheric conditions may have been unequally decomposed, will often afford an excellent illustration of the original differences in it, arising not only from a variation in the component parts, but also from the modified manner of their aggregation, in consequence of differences in cooling.

Some veins or dykes, as well of granitic as of other igneous rocks, afford excellent examples of their variable power of resisting the same order of decomposing influences according, chiefly, to the differences arising from modifications of cooling. Some granitic dykes, or *elvans*, as they are termed in Cornwall, show, as in the following section (fig. 4), an amount of decomposition gradually increasing towards the central portion. In this section *aa*, *bb*, and

* Hornblende is essentially composed of silica and of lime and magnesia, in variable proportions, these substances replacing each other, and sometimes also being partly replaced by protoxide of iron.

c represent the different parts of a granitic dyke, or elvan, traversing slate rocks, *d d*. Assuming, in this case, that the elementary com-

Fig. 4.



ponent parts of the dyke were originally the same, and that the differences found have arisen from variable cooling, as it is now well understood has frequently been the case, the decomposition has been effected according to the facility with which certain portions could be attacked by atmospheric influences and be subsequently removed. The two outward parts of the dyke (*a a*) are considered to be composed, as often happens, of a hard siliceous rock, the elements of the granitic matter having taken that form from comparatively quick cooling, so that this modification of it has resisted decomposition better than the rest. At *b b*, inside the hard rock, another modification, arising from more slow cooling, is supposed to exhibit a porphyry, some mineral, very frequently felspar, crystallizing out amid the base, itself less compact than the preceding variety. Not unfrequently in such cases the felspar is decomposed, and the insoluble portions even removed when directly exposed to the atmosphere. Still proceeding inwards, the rock becomes more and more granitic, until, finally, the central portions are well crystallized, and then exposed to the full action of the decomposing influences.

We often thus find, within a short distance, a good example of variable decomposition arising from differences in physical structure, the chemical composition of the mass remaining the same; a variation very instructive, since it enables the observer readily to appreciate the inequalities of surface which, in many regions composed of the same kind of igneous rocks, arise from changes in physical structure alone, some variations having better resisted decomposition or abrasion than others. At the same time he should carefully study the modifications in hardness, and the capability of resisting decomposition arising from changes in chemical composition, such, for instance, as those observable among the granites which occasionally graduate into schorl rock, in Devon and Cornwall.*

* The following may be taken as an estimated general view of the chemical difference between common granite, composed of two-fifths of quartz, two-fifths of

Of the curious forms assumed by granitic rocks from variable resistances to decomposition, those named the Kettle and Pans, at St. Mary's, Scilly (fig. 5), may be taken as a good example.*

Fig. 5.

While rocks of a generally similar chemical composition, such as those above noticed, are found to decompose in a variable manner, according to the different aggregation of their component parts, it would readily be anticipated that any rocks formed of different materials, brought together as sands and gravel, and subsequently consolidated by some cementing substance, would be found to decompose irregularly and according to the different powers of their component parts to resist the chemical and mechanical influences to which they may be exposed. It will soon be perceived that, taken generally, the cementing matter of sandstones and conglomerates decomposes first, liberating the grains of sand and the pebbles, that have originally remained such from their hardness, and which are thus ready to be again carried by moving waters to other situations, there to form the parts of new accumulations. The rapidity of

orthoclase, and one fifth of mica, and schorl rock, supposed, for illustration, the proportions varying materially, to be formed of equal parts of schorl and quartz:

	Granite.	Schorl Rock.
Silica	74·84	68·01
Alumina	12·80	17·91
Potash	7·48	0·35
Soda	–	0·98
Lime	0·37	0·14
Magnesia	0·99	2·22
Oxide of iron	1·93	6·85
Oxide of manganese	0·12	0·81
Fluoric acid	0·21	–
Boracic acid	–	1·79

* Though the true origin of the "Rock Basins," as they have been termed, is in general sufficiently clear, it may often have happened that, owing to a convenient situation, the Druids may have employed them for their purposes, either as they naturally occurred, or were artificially modified.

decomposition in such cases necessarily varies according to the nature of the cementing substance. A calcareous cement, though hard, will more readily give way before the chemical influences acting on limestones than ordinary siliceous matter, though the latter may be less compact; while a siliceous cement, if porous, may be more easily removable by the combined action of frost and thaw.

The hardest limestones, even those termed marbles when crystalline, will be observed to decompose on the surface.* The action is necessarily variable and dependent on the different resisting powers of the rock, on the one hand, and the exposure to the needful decomposing influences on the other. A crystalline and calcareous vein, running through an ordinary limestone, will often be seen standing out in salient relief, the arrangement of particles in the crystalline form, notwithstanding that the carbonate of lime is then generally more pure than in the body of the rock, being better able to resist atmospheric influences than in a less definitely arranged position.

Upon further examination it is perceived that not only the crystalline veins thus protrude upon the surface of the limestone rocks, but that many an organic remain does the same, and, in some instances, a limestone is only clearly distinguished as fossiliferous by this kind of decomposition, the common internal fracture ill exhibiting the fact. That this harmonises with the comparatively undecomposed condition of the crystalline vein becomes apparent when we examine the structure of these organic remains. The shells either retain to great extent the original crystalline or other definite arrangement of their parts, so essential to their well being when the animals of which they once constituted the hard portions were alive, or having been decomposed in the body of the rock during the lapse of time, the empty spaces, (or casts, as they are commonly termed) have been filled with crystalline carbonate of lime, which has percolated in solution through the pores of the rock into the cavities.†

By this kind of decomposition we often learn that many a limestone is really little else than a mass of organic remains cemented by a minor quantity of chemically deposited carbonate of lime. Some of the hardest limestones afford excellent examples of this

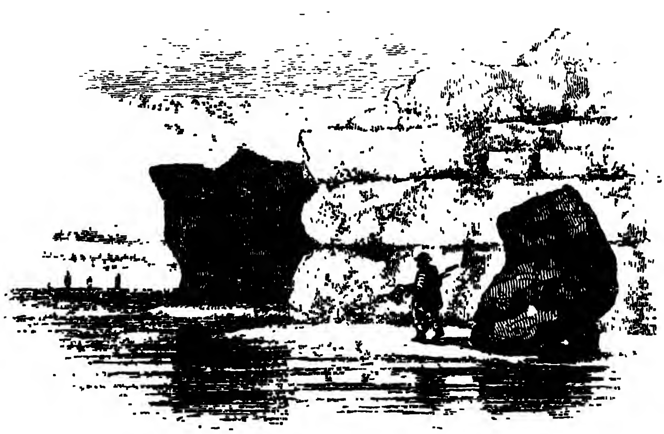
* This is often well shown in collections of antique marble statues.

† It was considered useless further here to remark on the composition of organic remains. It may, however, be noticed that the bones and teeth of fish, reptiles, birds, and mammalia have been often secured from removal by their composition, and that into the cavities left after the original decomposition of shells other less soluble substances than carbonate of lime have been infiltrated, such for example as into the cavities of the *Gryphæa incurva* and other shells, in the lias of Glamorganshire, where silica has replaced the original matter of the shells.

fact. The beds of carboniferous limestone of England, for hundreds of feet in depth, are occasionally found composed of little else than the disintegrated joints of encrinites, mingled with shells and a few corals.*

By the aid of decomposition we not only learn that many limestones are little else than such accumulations of the harder parts of molluscs and other creatures, many of which have lived and died in the places where we discover their remains; but we also find revealed the arrangements of the component parts of rocks, as well igneous as accumulated by means of water, which do not otherwise appear, arrangements of parts exceedingly important when we study the original manner in which rocks have been accumulated, or the modifications and changes to which, during the lapse of geological time, they have been subjected.† Many a sandstone, well *weathered*, as it is termed, will exhibit as beneath (fig. 6), a

Fig. 6



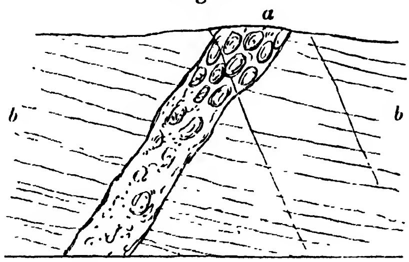
honeycombed and irregular appearance, arising from the different character at parts of the cementing substance, either original or subsequent to the accumulation of the rock, as the case may be,

* This fact may be well studied, among other localities, on the southern coast of Pembrokeshire, where the cliffs afford excellent opportunities of observing the mode in which the materials of its carboniferous limestone have been accumulated.

† As regards the weathering of calcareous rocks, it can be seen to great advantage on part of the shores and amid the islands of the Lake of Killarney, where the carboniferous limestone is hollowed into most fantastic forms. A well-known and strangely-formed rock, standing out into the Great Lake, known as O'Donaghue's Horse, and which so well illustrated this decomposition, was unfortunately thrown down by the action of the fresh-water breakers upon it in 1851 Carbonic acid in the waters of the Lake, near its surface, has acted very conspicuously in this locality.

and many another structure, also of importance, such as the concretionary structure of some igneous rocks, then alone becomes apparent. We should, for example, probably be ignorant, without *weathering*, of this arrangement of parts in the granitic or elvan dyke,* *a a*, cutting through slates, *b b*, at Watergate Bay, Cornwall, and figured beneath (fig. 7).

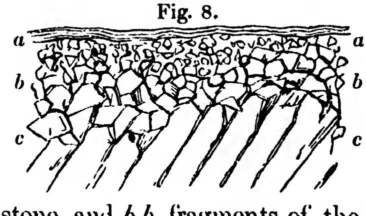
Fig. 7.



The division of rock masses by *cleavage* greatly aids their decomposition, since it renders them slaty, when this would not happen from any original accumulation of sand or mud in thin layers, one above the other, and the like arises from those separations in planes, named *joints*, more distant from each other, and which with the cleavage planes will be further considered in the sequel. By these means water more readily percolates through many rocks than it would otherwise do, and thus a greater amount of soluble matter may be attacked than would otherwise have happened in the same time.

Many hard rocks break up superficially in a manner showing little symmetry of form in the fragments, so much so that their shape seems more due to the irregular action of decomposing influences, than to differences of resistance from original structure. A compact limestone or hard sandstone may often be seen broken up beneath the soil, in the manner exhibited in the accompanying section (fig. 8), in which *a* represents the vegetable soil, *c c* a hard

Fig. 8.

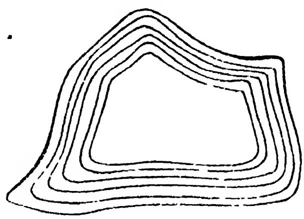


limestone or sandstone, and *b b* fragments of the same rock, largest

* This dyke is a compound of quartz, felspar, and mica, containing disseminated crystals of felspar.

towards *c c*, and evidently having constituted portions of the subjacent highly inclined beds, while the upper fragments are smaller and more confusedly mixed, though still angular. It sometimes happens when the rock, so broken up, is a sandstone that the chemical change of iron in the cementing matter subsequently to the formation of the fragments, is well seen. Upon breaking these fragments, sections, as beneath (fig 9), will often present themselves.

Fig. 9.



A central portion remains unchanged, surrounded by irregular zones (*b b*), commonly of a brownish red, arising from chemical action, by which the protoxide of iron has been converted into a peroxide. Similar changes of the protoxide of iron into the peroxide, are observable among the argillaceous limestones, such as the lias, and are indeed sufficiently common.

In some very earthy limestones, which may rather be considered to have been once silt, highly impregnated with calcareous matter, the disappearance of the latter in the higher parts of the rock, even to many feet in depth, has been so complete, and the peroxidation of the iron so extensive, that a rusty looking porous substance alone remains. Among some of the older accumulations such a rock may often be seen, and be found the only means by which beds, here and there containing a larger per-centage of carbonate of lime, can be traced or connected. Among the older rocks also, many a layer of a rusty colour shows a total disappearance of the carbonate of lime of the numerous shells which once constituted the bulk of the layer, their casts, or the spaces which they once filled, alone remaining, while the iron contained in the mud or silt which first enveloped them, has been converted altogether into a peroxide.

While thus the iron contained in many rocks exhibits a gradual change to a peroxide, many red marls and sandstones show an alteration from the peroxide of iron, giving a general red tint to these deposits, to a protoxide. Beneath the vegetation, and by the

sides of natural joints the red colour will be seen converted into a green or bluish green, the change being due to the effects of decomposing vegetation, which has robbed the adjacent peroxide of iron of a portion of its oxygen. This is a point of much interest when we study the cause of the streaks of green or bluish green amid the red marls and sandstones of different geological ages, and which have probably arisen from causes in operation at the period when the whole has been accumulated. When we examine into the variations and modifications of colour arising from the present effects of decomposing vegetation, the old changes have to be carefully separated from the modern, since both are sometimes exhibited in the same sections.

The observer must be careful, in his estimate of the amount of decomposition which rocks may sustain from atmospheric influences, duly to consider the power of vegetation to prevent, assist, or otherwise modify it according to circumstances. Vegetation may prevent decomposition, by presenting a certain barrier to the effects of sudden frosts and thaws; assist the action of rains by keeping the higher parts of rocks more permanently wet than they would otherwise be; or greatly modify it by the various effects produced by the kind of plants which may cover the land at given times; for a portion of country covered by forest trees would be differently circumstanced, as regards the probable decomposition of the rocks of which it is formed, than when the same portion was either broken for tillage or spread over with pastures.

As a whole, the study of the decomposition of rocks is one of much importance, since by it we learn a variety of facts connected with the original accumulation of mineral masses, with which otherwise we should be unacquainted, and at the same time it often teaches us properly to appreciate the changes and modifications which have occurred since such original accumulation. It enables us to form a correct judgment of the amount of matter which may thus be prepared for removal and for accumulation elsewhere. We see causes and effects that have been in operation whenever land arose from beneath water into the atmosphere, however modified these may have been by alterations of conditions, such as those now found between the tropics, and in the arctic or antarctical regions, or which may have taken place in the atmosphere of our planet from its earliest state.

CHAPTER II.

REMOVAL OF SOLUBLE PARTS OF ROCKS BY WATER.—TRAVERTINE AND CALCAREOUS BRECCIA.—CHLORIDE OF SODIUM IN SPRING WATERS.—SILICA IN WATER.—HOT SPRINGS.—SPRINGS ON THE OUTCROP OF BEDS.—SPRINGS FROM FAULTS.—CAUSES OF LANDSLIPS.

As spring waters are not pure waters, but hold different substances in solution according to circumstances, and as it is evident that at least, the bulk of such waters are only rains which have percolated through rocks, and variably pour out again according to conditions, the substances so in solution must have been removed from the rocks. However small the soluble matter found in any single spring may be, on the average, collectively its amount is considerable, particularly when we regard the changes which rocks must have undergone from this cause alone during the lapse of any geological time, when circumstances may have thus permitted the removal of soluble matter from any given mass of them.

With the removal of lime as a bicarbonate we are commonly familiar, since by the loss of the excess of carbonic acid required to retain it in solution, this substance is thrown down in different forms varying from a simple incrustation upon vegetable matter, or upon stones or rocks, amid or over which water containing it may flow, to hard and compact limestones, some taking a crystalline form, as is frequently so well shown in the beautiful stalactites and stalagmites of many caverns in limestone countries. It is no uncommon thing in calcareous districts to find the fragments of limestones which have been detached from faces of rock by atmospheric influence, firmly cemented together, as a breccia, by carbonate of lime, left by the waters which have percolated through them.

In the calcareous countries of the tropics, where evaporation is more rapid than in temperate climates, the deposit of carbonate of lime may often be studied with much advantage. Heavy rains falling amid a mass of vegetation, the decaying parts of which furnish the needful carbonic acid, carry this with them amid the beds, joints, and caverns of the limestones; carbonate of lime is thus re-

moved, and when the waters again emerge charged with bicarbonate of lime, and are exposed to the heats of a tropical sun, incrustations are formed in the shallow and slow-moving portions of the streams. Trees may even thus become imbedded by the shifting course of the waters, as is well seen at the Roaring River on the north side of Jamaica, where waters containing much bicarbonate of lime, after leaping over a cliff, run roaring amid a forest, the lower portions of the trees of which they encase with carbonate of lime, and shift their channels as new accumulations compel them to follow a new direction.

In shallow sheltered bays also of tropical coasts, to which water containing calcareous matter may slowly find its way, the solution becoming thus highly concentrated by evaporation as it flows onward, opportunities are occasionally afforded for observing the formation of the little rounded grains of calcareous matter in concentric coatings, termed oolites, a slight ripple being sufficient to produce a to-and-fro motion on the beach on which the calcareous matter is being deposited. Upon breaking these calcareous grains, sometimes a fine particle of common sand, or broken shell forms the nucleus, at others it would appear that a simple particle of the calcareous matter itself, before it became attached to any other solid substance, was sufficient for the purpose.

Though many countries show deposits of carbonate of lime from waters flowing over them, parts of Italy have so long been remarked on this account, that the name *travertino* has not unfrequently been given to such accumulations.* This deposit has also a peculiar interest in that land, inasmuch as we there sometimes find ancient architectural works, as for example, the remains of the temples at Pæstum, constructed of travertine, containing the remains of the same kinds of terrestrial and lacustrine shells which now exist in the vicinity, and become entombed in the travertine now forming. Of large accumulations of calcareous matter depositing under the atmosphere and not beneath bodies of water, the plains of Pamphylia would appear to afford a very striking example. The coasts of Karamania have long been known to present good instances of beaches

---

* Not only have we excellent opportunities of there studying the calcareous deposits thrown down from waters of ordinary temperatures, but those also from thermal springs, in which other substances are mingled in a manner to produce very interesting results. Of this kind is the intermingling of silica with the other deposits at the baths of San Filippo, where the waters have a temperature of 122° Fah^{t}. (one spring being about a degree higher), and contain in solution, silica, sulphate of lime, bicarbonate of lime, and sulphate of magnesia. The ground around is composed of travertine deposited by the springs.

consolidated by the percolation of carbonate of lime amid the pebbles, thus forming a conglomerate. We may thus obtain not only breccias and conglomerates upon the land, by the evaporation of water, charged with bicarbonate of lime, without the aid of lakes, but also sheets of limestone, the overflow of rivers and the shifting of their courses causing the necessary deposits. It would be desirable, where fitting opportunities for studying the latter kind of accumulations may be found, carefully to examine the differences between them and those deposits effected in tranquil bodies of water, such as lakes. We should expect, while the gradual rise and overflow of the rivers may here and there bury, by means of the calcareous deposits from them, the fluviatile or lacustrine molluscs living previously in favourable situations, that there would be much showing the drift of animal and vegetable substances borne onwards to localities where their further progress was arrested, and where they became entombed beneath the limestone afterwards formed over them.

Although limestone may thus silently and unperceived be transported from one locality to another, since the clearest waters may contain the bicarbonate of lime in abundance, many other substances are also, in a similar manner, borne onwards in solution; and it becomes desirable, in the present state of geological science, that the mass of this matter, and the proportions of the substances commonly composing it, should be examined. Something is done by every analysis made of spring and river waters; and the desire to obtain good waters for domestic purposes, has lately led observers to connect the rocks from which springs issue and afford the supply to rivers with the quality of waters; but it would be well more systematically to study the soluble matter conveyed away in this manner by moving water.*

It should be recollected that when rivers are swollen by rains, though substances in solution amid the rocks may be then forced more abundantly out of some than at other times, the amount of soluble matter is not increased in proportion to the water, since much rain or melted snow then runs off the ground without penetrating amid the rocks. Common salt (chloride of sodium) will be found more frequent than may usually be supposed in spring and

* Much may be accomplished by taking up the water in clean bottles, well-corking, sealing, and securing them; noting the state of the springs, streams, and rivers at the time as regards the quantity of the water in them, and by obtaining a section of the rivers at some convenient situation, and a proper insight into their velocities at the time of taking the water, so that a fair estimate may be obtained of the amount of soluble matter transported.

river waters. When we consider the number of rocks which, from their organic contents, we have reason to suppose were formed beneath the sea, and which have been deposits of mud, silt, sand, or gravel, now elevated into the atmosphere, so that rain waters percolate through them, we shall not be surprised at the presence of chloride of sodium, since it is to be expected that this and other salts in solution in sea waters would, formerly as now, be disseminated amid mechanical deposits effected in the sea.

Silica is well known as in solution in some waters; chiefly, however, found in appreciable quantities in those which are thermal. The geysers of Iceland have been long celebrated for their abundant siliceous deposits.* Silica has borne such a part in the consolidation of rocks, that wherever opportunities occur of observing the effects arising from the action of silica-bearing waters, they should receive careful attention. The manner in which silica may be taken up in its nascent state, and in which it is discovered in heated waters, are circumstances of much importance when we have to consider its mode of occurrence in veins, or its agency in agglutinating the particles of mud, silt, and sands in beds of rock. It is now known not only that certain plants require this substance, but that it is essential to some animals; so that the study of the mode in which silica may be taken up in solution, distributed, and used not only by plants and animals, but also for the consolidation and filling up of the fractures of rocks, is one of much interest.

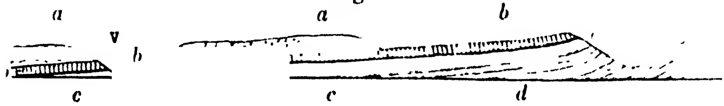
Springs are presented to our attention chiefly under two forms. First, from the combination of porous and less permeable rocks in such a manner that the water passing readily through the former, and with difficulty through the latter, lines of springs may form at any sides of hills or other exposures, where its outpouring is more easily effected than in other directions: and, secondly, from out of

* Sir George Mackenzie (*Travels in Iceland*) mentions that deposits from the Geysers extend to about half a mile in various directions, with a thickness of more than twelve feet. The leaves of birch and willow are fossilized, every fibre being discernible. Grasses, rushes, and peat are in every state of petrifaction. Very elaborate analyses of the Great Geyser waters by Dr. Sandberger and M. Damour, will be found in the sequel. From these it would appear that the silica constitutes about 0·55 of 1000 parts, including the water.

The siliceous deposits from hot springs (temperature 73° to 207° Fah.) in the volcanic districts of Fumas, St. Michael's, Azores, are important. Dr. Webster (*Edinburgh Phil. Journal*, vol. vi) gives an interesting account of them. The siliceous deposits are noticed as most abundant in layers from a quarter to half an inch in thickness, accumulated to the depth of a foot and upwards. Compact masses of siliceous deposits are mentioned as having been broken up and re-cemented by silica, and the compound is represented as beautiful. The height of some of this breccia is estimated at thirty feet, and the general accumulation, including a clay, also deposited from the waters of the hot springs, as considerable, forming low hills.

those of breaks and dislocations of rocks which have been termed *faults*, and which become channels into which waters are either drained laterally, or forced up from beneath. Let the following section (fig. 10) represent one of a country composed of different rock deposits, somewhat similar to those in our oolitic districts, for example, *a a* being portions of a porous and calcareous rock,

Fig. 10.



such as some of those oolites are, based upon a clay, *b b b*, itself reposing upon a sand, *c c c*, chiefly composed of siliceous grains, and this again resting upon a clay, *d*.

We should here have the conditions for a marked example of the springs of the first class. The rain falling upon *a a* would percolate through it, taking up calcareous matter by aid of the carbonic acid in the rain water, or obtained in its passage through the vegetable covering and soil. Not being able to permeate readily through the subjacent clay, *b b b*, it would be thrown out as spring water at the junction of the two rocks. This water would probably contain much bicarbonate of lime. The subjacent clay might furnish some water in the valley V, a slight portion of the rains finding its way amid the particles of clay, already moist. We will suppose that, as often happens, the spring water thus afforded would contain iron (from the decomposition of iron pyrites), and sulphate of lime (iron pyrites and selenite being often common in such clays). Beneath, in the two hills to the left of the section, the rain falling would not readily find its way from above to *c c*, though laterally this bed may be exposed to it, as a part is on the right of our figure. This bed has been considered as principally composed of siliceous grains, and to be based on a comparatively impervious bed, *d*, which may be a clay. Springs would find their way out of this bed in the valley V, and we should expect that, though they might contain certain matters in solution, these would not be the same, at least not in such abundance, as from the beds *a* and *b*.

A stream, therefore, flowing down the valley V, would collect waters differently charged with the substances which rains on their passage through the rocks had brought out in solution; and though the waters of such a stream would present us with a kind of mean of all the substances abstracted in solution from the various rocks,

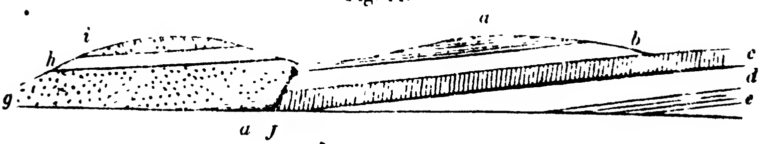
they would not show those obtained from any kind of rock taken by itself. These, consequently, would have to be studied where the springs flowed from each bed. The streams, moreover, contain the top waters which, during rains, flow over the surface, carrying off, independently of the matters mechanically transported, those which can be taken away in solution, and which had not formed component parts of any of the solid rocks passed over in their course, such matters being commonly derived immediately from animal and vegetable sources.

The observer would readily expect this simple mode of occurrence of dissimilar rocks, furnishing water holding different substances in solution, to be variously modified, so that while studying the kind of matter thus abstracted from rocks, he should carefully direct his attention to the connection of springs of this order with the kind of rocks traversed by rain waters.

The joints and cleavage among certain rocks greatly complicate the subject in some districts, and in others contorted and crumpled strata so occur, that long troughs and irregularly formed basins of water are held up amid the beds and rocks, pervious to water, in some localities, while dome-shaped masses tend to throw these reservoirs off in others. In the cases of such basins and troughs, the water remaining during the drier times may perfect many solutions, which, when the rainy seasons come to act, are borne away in springs, at that season only of importance.

Springs of the second class are commonly more constant as to the quantity and quality of the waters they deliver, and in this manner, when they traverse many dissimilar beds, furnishing the solutions of different substances, they are like the streams above noticed, as regards such substances. We do not, therefore, learn from them the kind of loss any particular rock may sustain from this cause, though they may be useful in showing the solutions delivered from the fissures. Let *f* in the accompanying section (fig. 11) be a

Fig. 11.

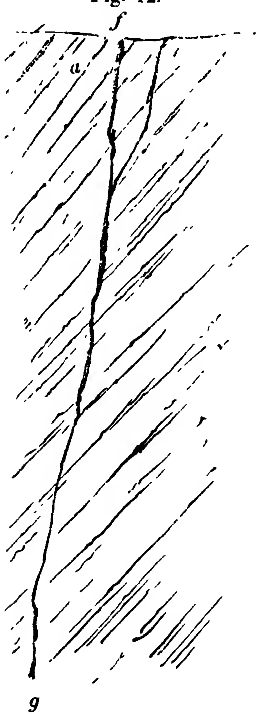


dislocation traversing various dissimilar beds, so that the bed *a* is thrown down, as it is termed, on the left, and that we find other and upper beds, *g h* and *i*, occupying the same general levels, as *a b c d* and *e*, on the other side of the fault. In such a case the

various waters percolating through the latter would find their way into the dislocation with those of *g*, on the opposite side, and the solutions derived from all these beds would be mingled in the waters of the fault, flowing out at *f* in greater or less abundance, according to circumstances. We have here merely regarded the solutions derivable from the waters percolating through the upper beds; but as in the greater proportion of faults we possess no means of judging of the depths to which the dislocation may descend, we cannot form a correct opinion of the kind of rocks traversed by them, and affording solutions beneath.

Thermal springs, not in volcanic countries, have been traced either immediately to these dislocations, or the evidence has been such as to lead us to suppose that they may be merely covered over by beds, through which a sufficient passage has been found for the discharge of the waters rising among dislocated rocks beneath. The case of the Bath springs is not improbably one of the latter kind, the heated waters rising through some of those dislocations or faults which traverse the older rocks of the district (coal measures, carboniferous limestone, and old red sandstone), covered over unconformably by the new red sandstone series and lias (as these beds are known to do many dislocations of such older rocks in that country), the waters thus finding their way through cracks or passages in the superincumbent beds.

Fig. 12.



Connecting the heat of thermal fault waters with the increase of temperature of the crust of the globe inwards, as inferred from the increase of heat as we bore artesian wells, or descend in mining operations, the temperature of such waters would always be considerable, were it not that such temperature may be much modified by the conditions under which the waters are borne upwards and discharged. Let *f g*, in fig. 12, represent a fault traversing various rocks to a depth at which the water in it obtains a high temperature. These waters could only be discharged at that temperature, if the rate of outflow were so considerable, and the volume of water so large, as to be uninfluenced by the

cooling conditions which would exist in the rocks through which they had to pass. Towards the surface, these rocks would take the temperature of the part of the world in which they may be situate, variable near such surface, but at a certain depth, according to latitude and local conditions influencing surface temperature, assuming a constant temperature unaltered by the climatal changes or modifications above. Between this fixed situation, which in fig. 12 we will for illustration assume to be at *a*, and that beneath, at *g*, where a very high temperature may exist, such as 212° Fahrenheit (the boiling point of water under a pressure of atmosphere equal to about 30 inches of mercury on the surface of the earth), the water in the cleft or fault, would be at intermediate temperatures. Some waters, supposing a ready discharge of them to exist laterally, might have a tendency to percolate through the adjacent rocks, and enter the main fissure at depths not far beneath that of the lowest constant temperature, thus assisting to cool the upflowing waters, independently of the decrease of temperature effected by that of the rocks themselves. No doubt, under the conditions supposed, the sides of the fissure would be heated at given depths beyond that temperature which, if the heated waters did not rise through them, they would possess, but the discharge of waters, as a whole constant, and other conditions the same, there would be a final adjustment of the order supposed. This would be a state of things conducive to the entrance of many substances in solution into the main fissure, which might not be introduced into spring waters, either at all or so readily and abundantly in the first class of springs. The greater heat, as the rocks increase in depth, and the permeation of waters through them, at high temperatures, would be favourable to the removal of silica, often perhaps, only to short distances, one kind of rock being modified by its gain in this manner, and another by its loss. Any thrown out in solution would be so much removed from them, to be employed elsewhere in the modifications now effecting on the surface, always assuming, for illustration, that the rocks traversed by the fissures furnished the matters held in solution by the waters flowing upwards through them. A supposition which will require to be modified if we consider that some substances or portions of them may be borne up into the cracks which had not previously formed parts of solid rocks. Under any view, the solutions contained in these fault waters, are conveyed away from the mouths of the fissures, and so much of them as have been added to waters percolating downwards from the atmosphere, or in any manner through or from the adjacent

rocks, has caused a loss to such rocks,* and afforded matter, capable of ready transport, to be employed, as circumstances may permit, elsewhere in the formation of solid matter, or as an addition to solutions in the waters of lakes and seas.

Deep mines afford opportunities for observing the rate at which rain waters may percolate through the body or fissures of rocks downwards, and analyses of these waters so obtained, give the substances they have, during the time of their passage, taken up in solution. In mineral veins, the waters which would remain in them, or flow out as surplus, being in some mines pumped out to depths of even 1800 or 2000 feet, we no doubt have surface waters descending further than they would otherwise do in the same time, *the check to their progress, interposed by the water disseminated* amid the adjoining rocks, or in the fissure, being thus removed, but at the same time the evidence as to the power of the surface waters to descend in the time that may be observed, and as to the kind of solutions effected by them in that time is valuable.

Great care is required to give due importance to local conditions in such investigations, such as the comparative readiness with which the waters may be conducted downwards by means of an unworked continuation of the mineral veins—having easy water communications with the workings in the mines, the absence or relative abundance of great joints or other fissures in the adjoining rocks, the chance of any rivulet or stream passing over, when swollen by rains, fissures or cracks communicating with the main vein, and the like.

In some coal districts, the beds of under-clay (as those are often termed which are found supporting, or intermingled with the coal beds) are usually so impervious to water, that where faults or fractures of beds are rare, the collieries are little troubled with water. This impervious character, employing the term in a general manner, is well marked in coal measure districts where, as in parts of South Wales and Monmouthshire, the beds having a slight inclination, and being cut through by mountain valleys, springs of the class first noticed are thrown out in lines, marking those of the coal beds; the waters percolating through them being stopped downwards by the under-clays. A system of deposits in which such beds and others of tough shale occur, would present difficulties to the ready percolation of the water downwards. At the same time, slight

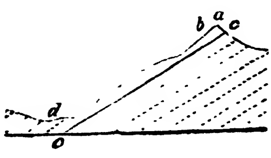
* Dr. Daubeny points to the very common presence of nitrogen in thermal waters as a proof that the water in them has been originally derived from the surface of the earth, that it there contained atmospheric air, and that, descending, this air was deprived of its oxygen by some process of combustion.

observation will soon show, that though water may not find its way in a sufficiently rapid manner in some collieries to be important, it is still most frequently there disseminated among the particles and joints of the rocks. Indeed, the manner in which water is disseminated among rocks is deserving of all attention, particularly when we regard it as a means by which a change and modification of chemical composition may be effected.*

The springs of the first class noticed as outflowing on the sides of hills and mountains, and on sea cliffs, are frequently productive of landslips, as they are often termed, the percolation of water in particular planes or directions so softening, or chemically removing the rocks, that a superincumbent weight not being held up by sufficient cohesion of the mass, is launched into the valleys or seawards as the case may be, thus producing a degradation of the land, throwing it into conditions fitted for more ready removal by rivers and the sea. Small landslips are very common, and are well seen in our oolitic districts, where the intermingled clays slipping into the valleys bring down the more consolidated superincumbent beds with them. In the coal district of South Wales good examples of a larger kind are to be found, and in many mountainous regions they are sufficiently common.

The slide or fall of the Rossberg or Ruffiberg on the 2nd September, 1806, afforded a memorable instance of the destruction produced by the percolation of water through bedded rocks in such a manner that, the needful cohesion of parts being destroyed, a great mass slid over an inclined plane of subjacent rocks. The following section (fig. 13) will serve to illustrate this fall, and some others

Fig. 13.



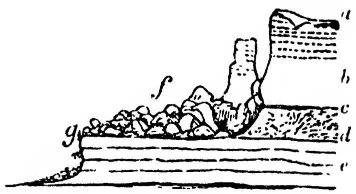
of the like kind. If in the mountain, *a*, water percolate through the porous strata *b* to the clay bed *c c*, the surface of the latter would become slippery, and the cohesion being insufficient to counteract the action of gravity, and no proper support be found

* The simple experiment of accurately weighing a piece of rock immediately after it is struck off in a metal mine or colliery, drying it thoroughly in a sand-bath, and then reweighing it, will often show more moisture to have been removed than might have been expected, the result being necessarily very variable from differences in the porosity of the substance.

below, the mass would be launched in the valley *d*. In the case of the Rossberg (a mountain 5196 feet above the sea), the upper beds were composed of conglomerates resting upon matter, which being partially removed by the percolation of water, and the beds at a high angle (about 45°), a launch of the upper beds took place, and a beautiful valley was covered with rocks and mud.*

The undercliffs between Lyme Regis and Axmouth, as well as those on the back of the Isle of Wight, illustrate the destruction of cliffs by means of springs. The following section (fig. 14) will show the conditions under which the undercliffs are produced at

Fig. 14.



Pinhay, near Lyme Regis. *a* is gravel; *b*, chalk; *c*, upper green sand, porous substances through which the rain waters percolate to the clay bed *d*, composed of the lower part of the green-sand beds *c*, and the upper part of the lias bed *e*, the upper green sands having over lapped the intermediate rocks observable in the south-east of England, and here resting upon the lias. The water being thus arrested in its progress downwards, escapes where it finds the least resistance; in this case towards the face of a cliff, originally formed by the action of the sea on the coast. The clay is gradually removed; the superincumbent green sand, chalk, and gravel lose their support, give way, and fall towards the sea. The lias *e* is not removed by the action of the coast-breakers so fast at the cliff *g*, as the rocks above are by the effect of the land springs, therefore the upper cliff retreats, leaving a mass of fragments confusedly intermingled at *f*, which has a constant tendency to move seawards, both from the destruction of the lias cliff *g*, by the breakers, and from the water percolating through the mass and loosening its base, so that it gradually moves towards the shore. The chalk and green-sand fragments are often sufficiently large and hard to afford, by their overfall, protection to the lias cliff; and thus a very confused but instructive coast section is exposed to the observer.

* The villages of Goldau and Busingen, the hamlet of Huelloch, a large part of the village of Lowertz, the farms of Unter- and Ober-Rothen, and many scattered houses in the valley, were overwhelmed by the ruin. Goldau was crushed by masses of rocks, and Lowertz invaded by a stream of mud. The lives lost were estimated at from 800 to 900.

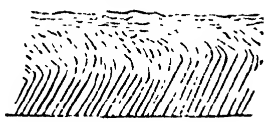
CHAPTER III.

SUBSTANCES MECHANICALLY SUSPENDED IN WATER.—TRANSPORT OF DETRITUS BY RIVERS.—DEPOSIT OF DETRITUS IN VALLEYS.—ACTION OF RIVERS ON THEIR BEDS.—REMOVAL OF LAKES BY RIVER ACTION.—FORMATION AND DISCHARGE OF LAKES.—LACUSTRINE DEPOSITS.

THE rain waters not absorbed by the rocks, act mechanically on the surface of the land, removing to lower levels such decomposed portions of the rocks as their volume and velocity can transport. The mixed effects of decomposition from atmospheric causes, and of soaking of the surface on hill sides, are often well shown in slate countries, a certain depth beneath the soil exhibiting the turning over of the edges of the slates towards the valleys;—as it were the tendency of the moistened matter of the surface to slide by its gravity to the lower ground.

The accompanying figure will illustrate this fact, one of much importance to the observer, for without attention to it he might commit grave errors as to the true dip of strata, when only a

Fig. 15.



slight depth of section may be exposed on a hill side. In the above figure the real dip of beds is represented as the very reverse of that which might be inferred from a hasty glance at the surface. Although it may be supposed that the difference between this sliding down of the surface towards the lower grounds and the true dip was always so apparent as not to be mistaken, the depth to which this action has occasionally extended is sufficient to justify great caution in many districts.

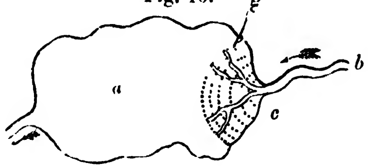
Upon a hill side and among the rills, hollows, and little plains which may sometimes be there found, an observer may often have good opportunities of studying the power of water mechanically to transport the decomposed portions of rock brought within its influence. He will soon perceive, that not only according to the

specific gravity, but to the form also of these portions is their removal effected, and that the manner of removal is of two kinds. In one case they are bodily carried in mechanical suspension in the water, while in the other they are swept onwards by its friction on the bottom. Small hollows will occasionally show the mode in which the matter so mechanically suspended or pushed onwards is brought to rest, and well illustrate the manner in which accumulations on the great scale may be and are effected.

If we suppose the observer placed in a granitic district where there is much decomposition of the felspar, such for example, as much of that near St. Austle, in Cornwall, he will soon find that while the fine decomposed remains of the felspar readily mingle with the waters which a heavy fall of rain may produce, the particles of quartz and mica are more commonly swept along the bottom, except where, from the slopes being considerable, the water may have sufficient rapidity to gather them up in mechanical suspension. While the volume of the particles of quartz may be larger, they are often more round, so that they are commonly, more readily pushed along the bottom than the grains of mica, not only flatter but possessing greater specific gravity.* The milky-looking water containing the decomposed felspar is borne onwards, slight deposits taking place where an expansion of the bed of the rill or rivulet may permit comparatively still water, until sufficient quiet is found for the general deposit, while the quartz or mica are strewed in little ridges, or thrust into holes, remaining there if the force of the stream will permit.

Much information may be derived as to the manner in which detritus is pushed forwards by rivers into bodies of still, or comparatively still, water, by observing sand brought down by a rivulet into a small pool of stagnant water, where the sand ceases to be forced forwards, and consequently accumulates. It will be seen that little delta-form heaps of sand accumulate where the rivulet enters the pool, on the fan-shaped tops of which the channels, over which the moving water pushes the grains of sand, are continually shifting. Let *a* in the following sketch (fig. 16) represent a pool

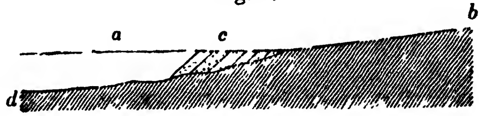
Fig. 16.



* The specific gravity of quartz is about 2·63, while that of common mica is 2·94.

of still water, into which a rivulet *b* pushes forward sand, then such sand will be found to accumulate at *c*, falling down into the pool *a*, in such a manner that a truncated heap of sand is produced, which increases superficially, as shown by the concentric lines at *c*. If now, attention be directed to the manner in which the grains of sand have been accumulated vertically, it will be found that they have been arranged as in the annexed section (fig, 17) in which *a*

Fig. 17.



represents the surface of the pool, *d* its bottom, *b* the slope of the rivulet pushing forward the grains of sand, and *c* successive coats of sand formed by the grains falling over into still water, such grains supporting themselves in the same manner as in any rubbish heap, from the top of which rubbish is continually thrown over. By diverting from their courses the small streams of water which run down sandy sea beaches on many coasts, very valuable information may be obtained as to the manner in which grains of sand are forced forward, and arranged by the pushing action of running water. When brought into the deeper pools among the sands, the deltas produced are extremely instructive, and in such cases the angle formed by the layers or coatings above each other, as the sands accumulate, is commonly found to be about 28° or 30°.

Having examined the mode in which decomposed portions of rocks, as well as those worn off by the friction of the streams, can be transported by moving water on the small scale, an observer will more readily appreciate the transport and deposit of detritus on the great scale in the course of rivers, with or without the intervention of lakes, as the case may be, and its removal towards lower levels and the sea. The manner in which it is either taken up in mechanical suspension, or merely shoved along the bottoms of rivers, is precisely the same in principle as in the little rivulets, though the effects, from their greater magnitude, are more striking in the one case than in the other. Larger masses may be shoved forwards, because the volume of water may be larger, sufficient to move those onwards, the resistance of which the minor streams could not overpower, yet the cause of their removal is of the same kind.*

* The following list of the specific gravities of some rocks which we have elsewhere given (*Researches in Theoretical Geology*, 1834), may be useful in showing their power of removal, in fragments or pebbles, by running water, all other conditions as

It will soon be perceived, that while at one time detritus only of a given magnitude, form, or specific gravity can be either pushed onwards by, or be mechanically suspended in, the rivers, at another the detrius, previously at rest, is readily borne onwards, and effects produced which, without the needful evidence, would scarcely have been considered probable from examining those produced during the ordinary condition of the same river. From the details given of the effects of great floods, as, for example, that of the Moray, much valuable insight may often be obtained as to the effects which, during a long lapse of time, may be produced along the line of a river course by repeated action of this kind.

The minor floods, commonly known as *freshets*, more or less common in all rivers, are geologically important, not only as respects the greater movement outwards of detrital matter at such times by the mechanical action of the water, but also as they often surprise terrestrial animals in low localities, and transport them with plants to still lower situations, or into the sea, in the latter case covering up these as well as estuary and marine animals in a common deposit of mud and silt.

In some countries the freshets, or rises of river, are periodical, produced from periodical causes inland, as, for example, those of

---

to velocity and volume of the water, and volume and form of the fragments or pebbles, being the same:—

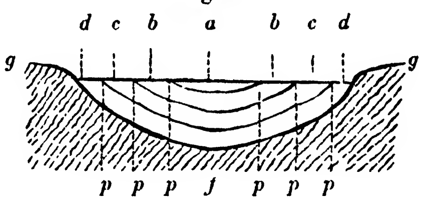
Calcaire grossier (Paris)	2·62
Chalk (Sussex)	2·49
Upper green sand (Wilts)	2·57
Lower green sand (Wilts)	2·61
Portland oolite (Portland)	2·55
Forest marble (Pickwall)	2·72
Bath oolite (Bath)	2·47
Stonesfield slate (near Stow-on-the-Wold)	2·66
Lias limestone (Lyme Regis)	2·64
Red marl of the new red sandstone (Devon)	2·61
Muschelkalk, fossiliferous (Gottingen)	2·62
Coal sandstone, Pennant (Bristol)	2·60
Coal shale, with impressions of ferns (Newcastle)	2·59
Millstone grit (Bristol)	2·58
Carboniferous limestone (Bristol)	2·75
Carboniferous limestone (Belgium)	2·72
Old red sandstone, micaceous (Herefordshire)	2·69
Old red sandstone (Worcestershire)	2·65
Silurian sandstone (Hartz)	2·64
Devonian sandstone (Ilfracombe)	2·69
Devonian sandstone, calcareous (Ilfracombe)	2·77
Silurian sandstone (Snowdon)	2·76
Argillaceous slate (Devon)	2·77
Carrara marble	2·70
Mica slate (Scotland)	2·69
Gneiss (Freyburg)	2·72
Domite (Puys de Dôme)	2·37
Trachyte (Auvergne)	2·42
Basalt (Scotland)	2·78
Basalt (Auvergne)	2·88
Basalt (Giant's Causeway)	2·91
Greenstones, various (different countries)	2·69 to 2·95
Sienite (Dresden)	2·74
Porphyry (Saxony)	2·62
Serpentine (Lizard, Cornwall)	2·58
Diallage rock (Lizard, Cornwall)	3·03
Hypersthene rock (Cock's Tor, Dartmoor)	2·88
Sienitic granite (Vosges)	2·85
Granite, gray (Brittany)	2·74
Granite (Normandy)	2·66
Granite, mica, scarce (Scotland)	2·62
Granite (Heytor, Devon)	2·66

the Nile, and deposits are then effected which do not receive additions until the annual time of rise again comes round. From this state of things to frequent alternations of floods and low states of rivers, there is every modification, so that the results of the deposits may be expected to be as modified as the causes of their production.*

When it is intended to ascertain the volume of water descending a river at a given time, and the amount of matter which may be then held in mechanical suspension by it, in order by a fair average to estimate the volume of water and the amount of matter, in mechanical suspension, borne seaward or into lakes during a year, or any amount of time thought desirable, much care is required so that the estimate may approximate toward the truth.

The section of a river presents us with waters moving with different velocities, and consequent transporting powers. Where the greatest weight of water occurs with equal velocities, there is the greatest pushing or forcing onwards of the bottom. If in the accompanying section (fig. 18) *g f g* represent that of a river

Fig. 18.



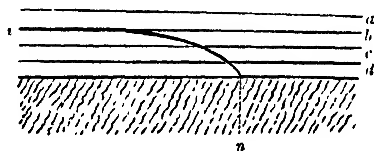
course, the greatest velocity of the water would be at *a*; and this will decrease towards the sides and bottom, where the friction would be greatest, as may be represented by the layers of water *b b*, *c c*, *d d*.

Let fig. 19 represent a longitudinal section of the layers of water corresponding with those in the cross section (fig. 18).

* As we have elsewhere observed (*Geological Manual*, 3rd Edition, 1833), there are few rivers more instructive than the Mississippi, man as yet not having effected many important changes on its banks, and we contemplate great natural operations, such as cannot be so well observed in those which have been more or less under his dominion for a series of ages Its course is so long, and through such various climates, that the freshets produced in one tributary are over before they commence in another; and hence arise those frequent deposits of detritus at the mouths of the tributaries. These latter have their waters ponded back, and, to a certain distance, stagnant, by the rush of the floods in the great river across their embouchures, and in consequence a deposit is effected, which remains until a subsequent flood in the tributary removes it. (*Hall's Travels in North America.*) Captain Hall states, that when the Ohio is in flood it stagnates the waters of the Mississippi for many leagues, and that, when the Mississippi is in flood, it dams up the waters of the Ohio for seventy miles.

Then assuming that the motion of the particles of water in the layer *a* is sufficient to keep some of the matter mechanically suspended, and some not quite so suspended, the latter will sink by the action of gravity; not, however, at once falling to the bottom, but entering the second supposed layer of water, *b*, where the velocity being less, it descends in less time through it, and so on through the other layers *c* and *d*, describing a curve *i n*. As regards the amount of mechanically suspended detritus, in such a section, we should anticipate that it would be very unequally dispersed.

Fig. 19.



Considering the section, fig. 19, to be one taken through the centre of the stream, and that we add other longitudinal sections taken through the lines, *p p p p p p*, fig. 18, we should have two series, one on each side of the central section, the terms of which could rarely agree, either in respect to the velocities of the water, the power of transport, or in the amount of detritus contained in them. So far, therefore, from it being easy to estimate the amount of detritus borne down in mechanical suspension, or forced along its bottom from friction by a river, it is a subject requiring very great caution and skill, even to obtain an approximate rough estimate of the fact.

When the water has been obtained from which it is intended to separate the matter borne down by rivers, and by a sufficient number of trials, in different parts of the river, to estimate the amount of such matter passing a given locality, it is needful not to evaporate the water, as has often been done, for by this proceeding the matter in solution is obtained as well as that in mechanical suspension. A measured volume of water should be passed through a filter, and the weight of the matter thus collected should be carefully ascertained.

Fully to appreciate the distance to which the various kinds of detritus may be borne by moving water until they be deposited, attention should be directed to the quantity and kind which can merely be pushed forward by a given velocity of such water, acting by friction on the bottom or sides against which it may pass,

and to the quantity and kind the same velocity may keep mechanically suspended at the same time.

As rivers are enabled to transport in mechanical suspension, or sweep forward detritus on the bottom, according in a great measure to their velocities, and as the latter, other things being equal, increase with the slope of the river channels, duly to estimate the power of a river to carry forwards to the sea or lakes the detritus thrown into the higher grounds, all the changes of slopes should be properly appreciated. Thus, if *a b* (fig. 20) represent the slope of a river in one place, and *b c*

Fig. 20.

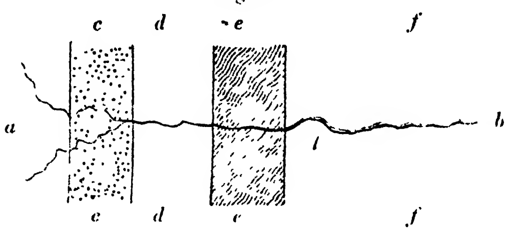
the slope of the same river in another, and the amount of water be neither increased nor diminished by tributary streams or diverging branches, the river will have greater velocity at *a b* than at *b c*, and consequently smaller pebbles and finer sand can remain at the bottom at *b c* than at *a b*.

The checks which a river may sustain in its course, such as by lakes, patches of level land, and the like, should be duly noted. Without this precaution it might be, and indeed has been, inferred that all the pebbles found far down a river course had been there swept by the river in its present state. While this is often true, care should be taken to ascertain that the needful conditions present themselves. Frequently, when a river takes its rise among high mountains, its onward course is, though often rapid, interrupted by tracts of level country, or even lakes, where the pebbles and heavier detritus are arrested; and yet pebbles derived from the rocks of the high mountains may be abundantly found in the river-bed further down than these obstacles, such pebbles having been brought to the channel in which the river now takes its course by previous geological conditions of the area. Thus, Alpine pebbles in some of the river courses of Northern Italy could not have been brought from the Alps into the plains of Lombardy, by existing rivers, since the Lago Maggiore, the Lago di Como, and others necessarily stop the progress of those borne from the high Alps by the torrents which now feed these lakes.

By attending to the kinds of rock traversing a valley, we

often find good opportunities afforded of studying the manner in which detritus derived from them, may become mingled by the action of the river waters. Care must, however, be taken to avoid considering as such those pebbles which may have been formed by the action of breakers while the land has been emerging from the sea, and which may have been at that time gathered into the lower parts of the valleys, or those which have subsequently been brought into them from the sides of hills or mountains by the long-continued action of rains and minor streams of water. Let *a b* in the annexed plan (fig. 21) represent the course of a river

Fig. 21.



through a district composed of marked, but different, rocks *c c*, *d d*, and *e e*, into a low country, where its movement becomes sluggish, and let the fall of the river-bed be such as to give sufficient velocity to a needful body of water to push or sweep forward pebbles of the size of an egg, where the full force of the water can be directed upon them. The river being capable of forcing forward pebbles of this size on the bottom, those of minor size, other things being equal, would be driven onwards, and there would finally be a size, weight, and form of detritus held up in mechanical suspension by the movement of the water. Under such conditions there would necessarily be a deposit of the detritus pushed forward by the water, wherever sufficient obstacles produced a less velocity in the river; and, as the river varied in velocity according to the quantity of water in it, the accumulations thus formed would possess an irregular character somewhat as in the annexed section, one through several minor deposits, depending upon small shifts in the direction and force of the propelling current.

Fig. 22.

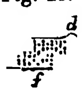
As the river in the plan (fig. 21) is supposed capable of shoving

pebbles onwards to the commencement of the low ground *f f*, irregular accumulations of pebbles would be expected at *l*, where the force of the river could no longer drive them forwards. It would not, however, be anticipated that the finer silt or mud could be there accumulated, except in very minor quantities in still places; since the power to keep such detrital matter mechanically suspended would be gradually lost by the river. Indeed the time required for the settlement of the finer parts, might be such that the whole body of water could continue to move through the lowlands in a turbid and discoloured condition, slowly parting with such detrital matter disseminated through it.

It would be expected under the conditions noticed, that accumulations would take place along the line of the river course; and that, unless these deposits were cut up by floods and so carried further onwards, the river-bed would be raised. The power of a river to keep its channel clear, and even to work it deeper, is commonly obvious where the river runs with rapidity; but it is not always so obvious, without careful investigation, that its bed has been raised, more particularly by the pebbles and sands shoved forward at the bottom.

In many plains, modified by rivers, the shoving forward of detritus is shown by the mode of its accumulation. Other accumulations so thin and wide spread as obviously to have been deposited from mechanical suspension are often, however, intermixed, so that both modes of deposit have contributed to the formation of these plains. Although we might feel certain that the beds of rivers must shift in great plains as such beds get raised, the waters taking the course of the lower levels, when such are presented, yet it is interesting to observe in some countries,—in Italy for example,—where artificial embankments have been formed to keep rivers flowing through fertile plains in their channels, that the beds of rivers become thus raised above the plains; and that roads rise up these banks on either side from the latter. In the little plain of Nice, the river ridges, formed by this cause, are striking, a loose conglomerate behind furnishing an abundance of pebbles to the river-bed. The following section (fig. 23) will serve to illustrate

Fig. 23.

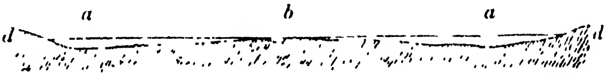


this fact, *a b* being the level of the country, in cultivation for many centuries, upon which artificial banks have been gradually raised

to *c d*, to protect the cultivated lands from invasion by the detritus forced forward by the river *e*. Thus the detritus which would have naturally escaped upon the plain has been raised artificially from *f* to *e*, notwithstanding the somewhat general plan of throwing the detritus thus accumulated over the sides upon the protecting banks *c d*, thus deepening the channel when the waters in the river may be sufficiently low for the purpose. The Po presents on the larger scale a well-known example of the rise of its bed, so that it is higher than the houses in Ferrara, and the like may always be expected under similar conditions.

A river may so raise its bed as for some time not to find a new main channel amid the adjoining plain, its turbid waters when in flood escaping over the banks without actually causing a breach, as is shown in the annexed section (fig. 24), where *b* represents a

Fig. 24.



river which has so raised its bed that there are tracts of country on either side at a slightly lower level. In floods such a river, spreading over the adjacent land, would leave all the detritus mechanically suspended in its waters, *a a*, and which did not retire with the water until its level was that of the banks of the river, upon the ground beneath up to the rising slopes *d d*, thus eventually filling up the depressions. The more common action of a flood is as represented in the section beneath (fig. 25), where a river (*b*)

Fig. 25.

not raising its bed (the flood waters merely removing mud from the bottom, the only sediment there collected), the overflow of turbid water (*a a*) returns to the river bed, depositing only such matter in mechanical suspension as the time of repose may have permitted. In these ways much sedimentary matter is distributed over plains during floods.

The matter pushed forward by rivers, or held in mechanical suspension in their waters, has hitherto been regarded only with reference to the removal of that arising from the decomposition of rocks by atmospheric influences. We have now to consider the erosion of clays, sands, and gravels, and of hard rocks by means of the rivers themselves.

In many a river course it may readily be observed, that incoherent sands and gravels are cut into by the mere friction of the water, even when clear. That such a moving body should so act would be expected, and no doubt we should also anticipate that amid incoherent, or easily-removed substances, any modification in the course of a river would speedily produce change in other parts; but it is, nevertheless, extremely interesting to experiment on the course of streamlets passing among sands: as, for instance, on some extended shores at low tides, and trace the effects of even slight alterations in the stream courses. The cutting into one bank throws the water upon another, not previously worn away, and the whole bed of the stream gets modified. Such experiments tend to make us more readily appreciate those modifications of rivers, from the actual cutting powers of their waters, which are seen on the great scale in some parts of the world. They also show the distances to which the fall of a cliff, the filling up of a cavity, by which, as forming a lake, the force of a flood may have been previously stayed in its full course, and other obvious circumstances have produced modification and change.

There are few persons who have not noticed the manner in which rivers are disposed to take serpentine courses in level countries, a fact as easily observed amid the meadows of the flat portions of many valleys, of very limited dimensions, as among the vast bends of the Mississippi, or any other of the great rivers flowing under similar conditions. The rivers, by their friction, cut into the ground presented to their course, and by working away the earth, clay, sands, or gravel, of bend against bend, modify their channels. The waters necessarily cut away such banks at the bottom of each bend. Hence, if two bends be opposite to each other, as those in the next sketch (fig. 26), are at *a*, *b*, and *c*, the

Fig. 26.

river will tend, by continued erosion, to approximate them to each other, so that they finally meet, and the river course becomes shortened by the amount of the bends previously passed over.

Although some effects must follow the action of clear water upon bodies, the parts of which have not sufficient cohesion to resist removal, it is by the assistance of matter either mechanically suspended in, or forced onward by the water, that rivers most

readily cut into their channels and erode their banks. By this assistance they wear even into hard rocks, removing the obstacles impeding their courses, and which prevent the formation of a convenient general slope. As among the simplest forms in which water acts by aid of mineral matter upon rocks, we may take the *vertical holes drilled in even some of the hardest by means of pebbles so situated, that* a rotatory action is given them, each in one place, by moving water. These are well known in many situations, where bars of rock stretch across river beds, and falls of water are thus produced. A pebble borne down by floods gets so established in an eddy that it remains there, and by constant friction, works a vertical hole downwards, sometimes to the depth of several feet. In some situations, where the obstacle has been much lowered by the erosive action of a stream, sections of the annexed kind may be seen. In rare instances the pebble, as at *a* (fig. 27), may still be seen, the section having been such as not to

Fig. 27.

have allowed it to fall out. In some situations this drilling into bars of rocks must have tended considerably to their ultimate removal.

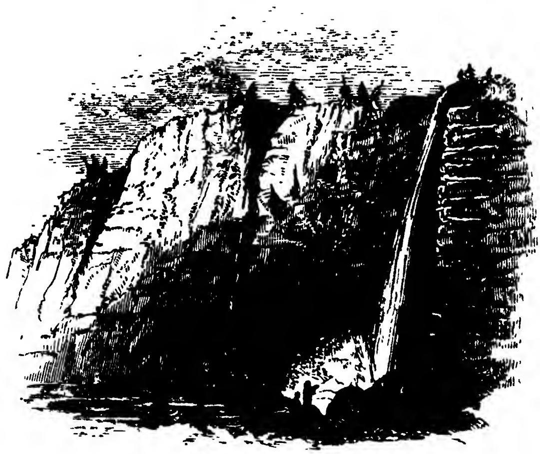
It is, however, when a river is in flood, large pebbles grinding and driving against rocks which may be exposed to the fury of the torrent, and minor detritus, either hurried onwards on the bottom, or in mechanical suspension, grating against and rasping, as it were, such obstacles, that the erosive power is most effective. Huge blocks are forced onwards, leaving the furrows which have marked their course to attest that course in some situations, while the finer friction of small pebbles and sand produces a smooth surface in others.

When endeavouring to ascertain the abrasion which may be due to rivers, the amount of decomposition which any rocks in their course may have suffered, prior to the supposed abrading action, should be carefully estimated, so that too much importance should not be given to such action. It being known that the decom-

position of many rocks is greatly assisted by such rocks being kept alternately in a wet and dry condition, the observer should notice if the water in any river course he may study, rises and falls, and in a manner sufficient to have an appreciable influence on the rocks washed by it.

Much care is required when we seek to refer the formation of a ravine through which a river may find its way to the cutting power of the river itself. There is no want of evidence that even minor streams, more particularly when swollen by rains, cut channels for themselves in various directions. In many a mountain region this is a fact of common occurrence. A little study will show the observer that some ravines are cut back very readily when, as beneath (fig. 28), beds, horizontal, or not far removed from that

Fig. 28.

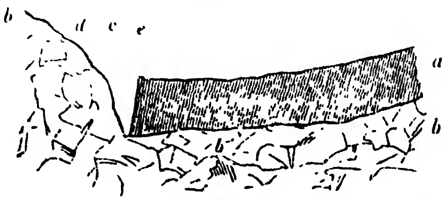


position, and composed of comparatively hard rocks, such as sandstones, are based upon softer substances, such as clays or shales. From the combined action of atmospheric influences, and of the falling water, with sometimes also the aid of water percolating between the hard and soft rocks, the lower beds give way, and being composed of easily-comminuted substances, are soon removed in mechanical suspension by the torrent, while the hard rocks, losing their support, are precipitated to the base of the fall. This mode of cutting back a channel, with vertical or nearly vertical walls in the first instance, however they may be afterwards modified by subsequent falls, or erosion by small streams, may be as well seen in hundreds of little brooks, where the needful conditions of hard and soft and nearly horizontal strata are to be found, as in the

valley of the Niagara, where the production of a ravine of this kind is exhibited on so large a scale.

If a barrier, such as a lava current, be suddenly thrown across a valley, the waters behind it, upwards, are necessarily sustained to the height of the lowest part of the new obstacle opposed to their further progress downwards. Should a section be presented to the attention of an observer, such as that beneath (fig. 29),

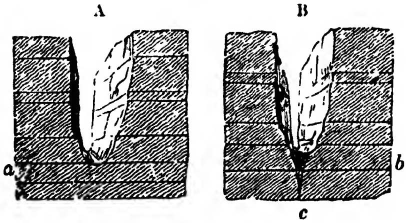
Fig. 29.



where a lava current, *a*, crosses a pre-existing valley in granite, *b b*, *d e* being a ravine, with *c* a river running through it, he should see if the stream of lava, *a*, has been actually cut through, or if it has never completely filled the valley, so that a space may have been left between the high part of the lava, *e*, and the bank of granite *d*, through which the waters readily found their way, the modifying action of the atmosphere and the river giving the fallacious appearance of a ravine wholly cut by the latter.

The observer will have carefully to distinguish between ravines which the rivers may have cut and those which are mere cracks or *rents* through which the drainage waters of any district may happen to find their way. Therefore he must carefully search for evidence sufficient to prove that the ravine may belong to either the one or the other of these classes. Let A and B (fig. 30) represent sections of

Fig. 30.

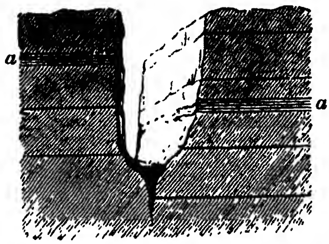


two ravines. In general appearance they might correspond; and even supposing a crack or rent, it may have been such as so slightly to move the opposite masses of rock as to be inappreciable. The geologist should endeavour to trace some bed of rock, such as *a*, unbroken from one side to the other, across the course of the river. Should he discover such a bed thus fairly connecting the sides of

the ravine together (no twist in the crack or rent presenting a fallacious appearance of an unbroken bed), the ravine may still not be due to the cutting action of the river itself, for it may have been a channel of communication from one body of water to another at a time when the land may have been sufficiently submerged for the purpose. Hence fair evidence would still be required to show that the river really cut the channel.

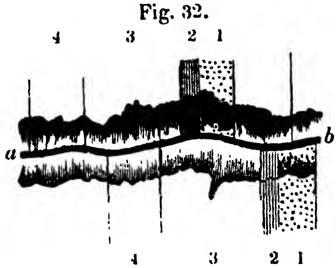
If the observer should be unable to trace the rocks unbroken across the ravine, the evidence would remain uncertain, for under the supposition that the sides so correspond as to render a dislocation doubtful, blocks of rock, pebbles, and sand, may as well cover a crack, such as *c* in B, as a continuous mass of rock. Should, however, the beds on either side of the ravine, if prolonged, not meet, that is, if, as in the following section (fig. 31), a horizontal

Fig. 31.



and marked bed *a*, be higher on one side than on the other, he will see that the line of ravine corresponds with a line of dislocation where this want of correspondence of sides is apparent, and by further search he should ascertain if this dislocation can be traced in the same line. Should this be so, it still remains to be ascertained, if the river has really done more than modify the effects of an action, along the line of dislocation, by which the ravine may have been originally worked out. If, instead of horizontal, we find vertical beds of rock, as in the annexed map-sketch (fig. 32),

Fig. 32.



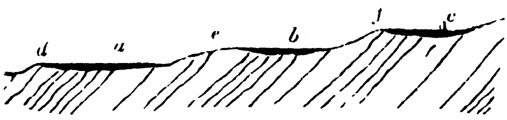
in which *a b* represents the course of a river through a ravine, and that a marked series of beds, 1, 2, 3, and 4, do not correspond if

prolonged across the river, then also it would be evident that the latter flowed in a line of a dislocation.

Should the rise of the river-bed be such that a series of falls be found at the higher part of the ravine, so that eventually the level of the river-bed be equal to its most elevated portion, it will be evident that no strait with water, in the manner of a sea channel, was the cause of the excavation, since by submerging the land, the ravine would merely form an arm of the sea, and be liable to be filled up by the detritus borne by the river from higher levels into it.

Upon tracing up lines of valley for the purpose of studying any modifications they may have sustained from the action of rivers and other running waters upon them, it will often be seen, particularly in mountainous regions, that level spaces present themselves, having the appearance of lake bottoms, the river meandering through these plains, and not unfrequently finding its way to lower levels through gorges or ravines of various magnitudes. It is generally supposed that by lowering the level of the lake outlet, the barrier ponding back the water has been removed sufficiently for its passage under ordinary circumstances onwards, it being merely during very heavy floods, that any water is spread over these plains. On the small as well as the large scale, this explanation would often appear probable. If, as in the following section (fig. 33), supposed to represent three lakes, *a*, *b*, and *c*, on the line of a mountain valley, the erosive action of the river could lower the barriers *d*, *e*, and *f*, the cavities *a*, *b*, and *c*, would cease

Fig. 33.

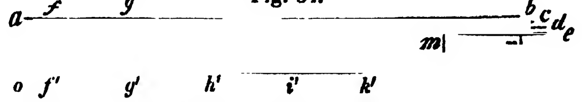


to be filled by water, and we should have plains in their stead, the old bottoms of the lakes, with the river meandering through them, and rushing through gorges or ravines at *d*, *e*, and *f*.

With respect to the effects produced by the cutting back of ravines to such bodies of water, once supposed capable of causing overwhelming floods, at lower levels, it should be observed that the depth of water at lake outlets is generally inconsiderable, so that the letting out and lowering of the lake waters would be gradual. To illustrate this, let the subjoined section (fig. 34) represent the case of a river cutting back its channel, in the manner of the Niagara (assuming that conditions were favourable for so

doing), towards Lake Erie, so that the latter became drained by the operation. Let *h e* represent the slope, exaggerated, of the lake bed from *h*, where the surplus waters are delivered over the barrier ground, and *f′ o* the level of the river below the falls cutting back the channel. Supposing *f f′* to represent the place of the falls, at

Fig. 34.



any given time, it is clear, the same effects continuing, that they may be further cut back to *g g′* and even to *h h′*, without diminishing the quantity of water in the lake. Once, however, at *h h′*, every succeeding cutting will occasion more water to pass over them, by draining the waters of the lake to the level of the top of the new falls, so that when these have retreated to *i i′*, the surface of the lake will sink to *i c*, and the mass of water, over the whole lake, and above the new level, will have passed over the falls in addition to the ordinary drainage discharge. This addition would add to the velocity and cutting power of the falls, which would be expected, all other conditions being the same, to retreat more rapidly to *k k′*, reducing the general level of the lake to *k d* in less time than it reduced it from *h b* to *i c*. In like manner, the level of the lake would be reduced to *n e*, which we may assume, for illustration, as its greatest depth; but every succeeding retreat of the falls lowering the general level so that the lake presented a minor area, the lake waters discharged would gradually become less until, finally, nothing more than the river would meander through the drained bottom of the lake. In considering the mode in which a lake may be drained by the cutting back of the outlet river channel, it should not be forgotten that, when large, the average loss from evaporation becomes less as the surface is diminished, so that the supply by the tributary rivers and streams is not much diminished by this cause, and more water finds its way through the outlet to the lower levels.

In volcanic regions we may expect a modification in the drainage of valleys by the flow of lava currents across them, and lakes may be formed in Alpine regions by the fall of masses of mountain into narrow valleys. From the former cause many permanent alterations in the drainage may be effected, the dammed-up waters finding a new outlet, more particularly amid accumulations of ashes and cinders In the case of a lava current traversing a valley, the deepest part of a lake thus formed might be at the lower part, as in

the annexed section (fig. 35), where the previous slope of a river-bed has been interrupted by the flow of a lava current *b* across a

Fig. 35.

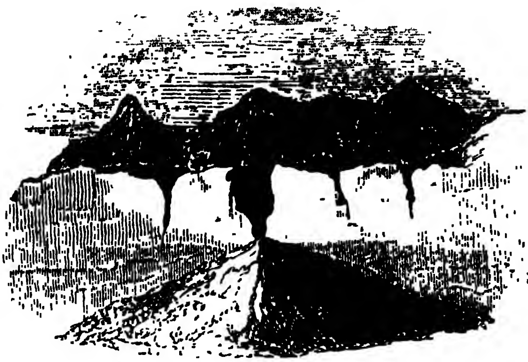
valley, so that the river waters are ponded back, and form a lake at *a*. Supposing that a lava current fairly stopped the river course, even rising somewhat on the opposite side of such a valley, and thus preventing the conditions noticed above (p. 36), such a barrier might long remain, the stoppage of the river waters preventing any kind of detritus, which previously had been forced onwards along the bottom, from further progress, at the same time causing much of the mechanically suspended matter to fall. Both conditions would be favourable to the filling up of the lake, such deposits again to be cut through, should the barrier of the lava current be eventually removed. And it is to be observed that the cutting away of the barrier would be more easily effected when the lake was filled up, and gravel and sand could be brought to scour and wear away the channel of the rapids or waterfalls from *b* to *c*.

When mountain masses have fallen across narrow valleys, as they are known to have done, and have ponded back the waters, it may readily happen that debacles may be formed, producing very great effects at lower levels, and causing the removal of masses of rock under such conditions, which the ordinary condition of the waters in the valley, with every regard to floods, would appear to render improbable. The observer may learn to appreciate the effects of such falls by throwing a dam of loose sand and gravel across any small stream, so that the waters be ponded back. At first the removal of the barrier will be slight, but after a time the waters rush out, sweeping a part of the dam before them, and removing, in their course downwards, stones and blocks which their vegetable coatings show have for years well resisted all ordinary floods.

Sometimes also in mountain regions, a cross valley may, from a thunder storm falling upon the area which it drains, thrust forward such a mass of rubbish across a main channel as to pond back its waters, which finally clearing away the barrier thus formed, rush suddenly onwards to lower levels. At other times the effects of a

tributary, delivering itself at right angles, or nearly so, to the main river, are more gradual; and in parts of a chief valley, where the fall of the latter is not so considerable as to produce a rapid current, more permanent changes are produced. The annexed sketch represents one of those cases, not uncommon in some regions,

Fig. 36.



where a tributary comes through a lateral gorge, high above the main valley, thrusting forward the detritus borne along it, so as to form a sort of half cone. The increase of such a mass will modify the line of the main river, if the latter be unable to remove the detritus thus borne across its course. In favourable situations, such as in some parts of the Alps, cottages and cultivation will be seen on those parts of the mound where the more or less divided streams of the tributary do not rush furiously onwards to lower levels.

Among the causes of debacle and change in drainage depressions, we should not omit the consideration of glaciers falling across valleys from adjacent heights, since the great debacle down the valley of the Rhone in 1818, is still fresh in the memory of many who witnessed its transporting power, and who would scarcely otherwise have been disposed to credit the effects produced. After successive falls from the glacier of Getroz, during several years, into a narrow part of the Val de Bagnes, in the Vallais, the accumulation finally became such that the waters of the Dranse, which previously found their way amid the fallen blocks of ice, were ponded back. A lake was thus formed about half a league in length, and it was estimated to contain 800,000,000 cubic feet of water. By driving a gallery at a lower level in the icy barrier, this quantity was supposed to be reduced to 530,000,000 cubic feet, a mass of water which, effecting a passage between the ice and the rock on one side, was let off in

about half-an-hour down the Val de Bagnes into the valley of the Rhone, and thus into the lake of Geneva, where fortunately, by the spread of the waters, their destructive force was lost. Huge blocks of rock were moved by this debacle, and a great mass of matter swept away to lower levels.

Mention has been already made of the deposits effected in the still portions of stream courses, and of the inclined angle which the layers of sand and gravel take, after being forced along the bottom of the stream bed, and thrown over little delta protrusions into the pools of water. The mode of detrital deposit to be observed in lakes is the same as in little pools, the difference is chiefly in the magnitude of the accumulations. The little pools differ principally from lakes from being liable to be swept by floods, and the deposited detritus to be thus once more lifted and borne onwards, which does not happen in lakes of fair magnitude. Moreover, discoloured flood waters spread over the pools, and not over pieces of water deserving the name of lakes. Lakes necessarily vary much as to the repose of their waters according to their depths. In the deeper parts of such a body of fresh water as that of the lake *of Geneva,* there is no cause for movement from altered* temperature of the water, for experiments would appear to show that this temperature always remains the same at the great depths, that of the greatest density of fresh water being found at all seasons of the year. In such situations also waves raised by winds on the surface are not felt, and whatever chemical or mechanical accumulations there take place would remain undisturbed, so long as the present conditions are continued.

In the shallow parts of the same lake, and necessarily also in shallow lakes generally, the waves (sooner raised in fresh water lakes than in the sea by the same force of wind, because the fluid put into motion is of less density) stir up the finer mud and silt, while the breakers act upon the shore, and for the time keep heavier matter in motion and mechanical suspension. As, therefore, the deep cavities holding lakes become filled up, there may be an irregularity in part of the accumulations of the higher portions not observable beneath.

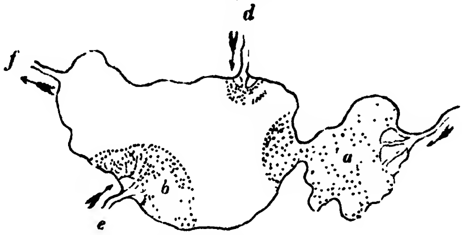
If attention be directed to the mode in which detrital matter is protruded into great lakes, such as those of North America, Switzer-

---

* In a series of soundings of the lake of Geneva, made in 1819, and chiefly undertaken for the purpose of seeing how far the temperature of the water in it corresponded with that assigned to the greatest density of fresh water, an account of which was published, with a chart, in the 'Bibliothèque Universelle,' for 1819, we found the greatest depth of the lake to be 164 fathoms, or 984 feet, opposite Evian.

land, or Northern Italy, it will rarely happen that the contributing streams or rivers are not found to pour in detritus of various kinds and in different ways. Let us consider that the accompanying plan (fig. 37) represents that of a lake divided into two unequal portions, and that it is supplied with water, in addition to the rain which may fall upon it, by the rivers *c*, *d* and *e*; that *c* is a chief river, draining a large district, and *d* and *e* two torrents, descending occasionally from adjacent mountain heights with great force, while, at other times, they contain little water.

Fig. 37.



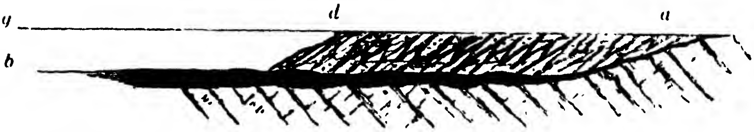
Let us further suppose that the waters of the river, *c*, are generally turbid, like those of the glacier rivers of the Alps, and that they vary in quantity at different times, so that the river both forces forward and holds mechanically in suspension variable amounts of matter. From such conditions as these we may assume that, though variable, the accumulations, brought down into the lake by the river *c*, would still be more uniformly spread than those resulting from the sudden rushes of water down the torrents *e* and *d*, the stones or pebbles, borne forwards by the latter, being larger than the detritus forced onwards by the main feeding river *c*.

In order to appreciate the difference of accumulation arising from these conditions, it may be desirable to assume that the depth of the lake is uniform, or nearly so, throughout, though of course the original form of the lake basin would influence the products. The river *c* would accumulate the detritus it can force along its channel, in the manner previously noticed, while at the same time it would discharge a body of turbid water into the still waters of the lake. The force of the former is checked by the latter; and the turbid water, being heavier than that of fresh-water lakes, would sink in clouds toward the bottom, as may be seen where the Rhone enters the lake of Geneva, and in various other similar situations. The velocity with which the turbid water would enter the lake would carry it to various proportionate distances, until its motion became finally checked. It is, however, interesting to

observe that, from the difference in specific gravities, when turbid waters fall to the bottom, these steal quietly upon that bottom for considerabe distances, it being long before they part with the fine matter which they hold in mechanical suspension. The fine matter brought down by the Rhone is found in mud beneath the still deep waters of the lake of Geneva, many miles beyond the discharge of the turbid waters of the river into that lake.*

Assuming the depth of the lake to have been such that turbid could so creep beneath the clear waters as to form a deposit of mud or clay, we should have the bottom of the minor division of the lake coated with this finely-comminuted matter, while a delta-like protrusion of the sand and pebbles was formed over it. Supposing the commencement of such accumulations to be in a rock cavity, the basin of the lake, we should expect them to take somewhat of the form seen in the following section (fig. 38), where *a* represents

Fig. 38.



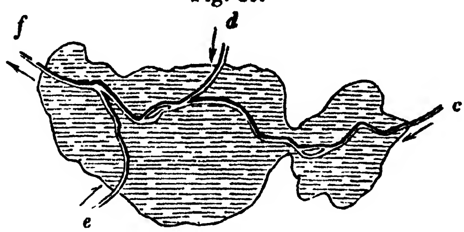
the first gravel and sand deposits, forced over at *c*, *b* mud, gradually accumulated over the rock basin, *d* the advance of the delta over the mud, and *g* the surface of the lake beyond the delta. Under such conditions we should have irregular beds of sand and gravel, with occasional patches of clay, the result of deposits in local stagnant places, based upon a clay which here and there, in its upper portion, might contain sand or sandy clay, the effects of floods carrying such matter in mechanical suspension beyond the delta into deeper water, and there depositing it upon the mud.

Still referring to the plan, fig. 37, we should expect the accumulations at the junction of the torrents, *d* and *e*, with the lake, to be much modified in character. To render the case more illustrative, we may consider that, from the nature of the rocks traversed by the respective torrents, little else than fragments of hard substances are shoved forward by *d*, while much earthy matter and soft rocks, easily comminuted by friction, are mingled with the harder fragments thrust into the lake by *e*. If a small amount of earthy matter be carried forward by *d*, the accumulation where the torrent enters the lake would form little else than a protruding mass of fragments,

* If a long trough be filled with clean water, and turbid water be very quietly poured into it at one end, the mode in which the latter finds its way beneath the former will be at once seen.

composed of beds different in position, but dipping at angles varying probably from 20° to 30° around the general curve of the protrusion; while such finely-comminuted matter as was held in mechanical suspension would descend to the bottom, and steal along beneath, as previously mentioned, adding to the mud derived from the chief stream *c*. The accumulations formed at *b* by the torrent *c*, would be of a mixed character between those produced by *c* and *d*. These causes continuing, the lake would be eventually filled up by clays, sands, and gravels brought into it by the rivers and torrents, the surface waves acting upon much of the higher accumulations as the general depth decreased. Finally, the outfalling river *f*, clear as that of the Rhone, where it quits the lake of Geneva, while the lake lasted, would be joined to the river *c*; *d* and *e*, as two tributary streams adding their waters to it, and the whole would traverse a plain, much as represented beneath (fig. 39), muddy sediment being added to the surface of the plain from time to time by floods, and the torrents still thrusting forward fragments of rock and pebbles where they joined it.

Fig. 39.



Great modifications of the mechanical accumulations here noticed will readily present themselves to the attention of an observer; aud, if he will combine some of them with the chemical deposits previously noticed, and add the harder parts of the animals which have either lived in, or been drifted into, the lakes, as also the leaves of trees and other plants, and the branches and trunks of trees which may eventually fall to the bottom after having been borne onwards sometimes quietly, at others confusedly and rapidly, he may better appreciate the still greater modifications to which lacustrine accumulations may be subject.

CHAPTER IV.

ACTION OF THE SEA ON COASTS.—DIFFERENCE IN TIDAL AND TIDELESS SEAS.—UNEQUAL ABRASION OF COASTS.—SHINGLE BEACHES.—CHESIL BANK.—COAST SAND-HILLS.

BEFORE we consider the accumulations effected in the sea, it is desirable to call attention to the action of the sea on coasts, since that action often contributes, in no small degree, to the matter of which such deposits are formed.

The sound produced by the grating and grinding of the pebbles of a shingle beach, even when the breakers on shore are comparatively unimportant, can scarcely have escaped the attention of those who have, even for a short time, visited coasts where such beaches, and they are common, are to be found. It will soon be apparent, that this friction, if continued for ages, must not only wear down the pebbles to sand, but grind away and smooth off even the hard rocks exposed to such powerful action. It is, however, when the observer sees the huge masses of rock moved by breakers arising from a heavy gale of wind, blowing on shore from over a wide spread of open sea, or from the long lines of wave known as a *ground swell*, that he not only learns to value the force of the water taken by itself, thus projected against a coast, but also the additional power it possesses of abrading the cliffs which may be opposed to the breakers by the size and abundance of the shingles they can then hold in mechanical suspension.

Properly to appreciate the power of breakers, a geologist should be present on an exposed ocean coast, such as that of Western Ireland, the Land's End (Cornwall), or among the Western Islands of Scotland, during a heavy and long-continued gale of wind from the westward, and mark the effects of the great Atlantic waves as they break and crash upon the shore. He will generally find in such situations that, though the rocks are scooped and hollowed into the most fantastic forms, they are still hard rocks; for no others could long resist the breakers, which, with little intermission, act

upon them. Not only blocks of rock resting on the shore are driven forward by the repeated blows of such breakers, but those also firmly bolted down on piers are often thrown off and driven aside in far more sheltered situations. The history of many a pier harbour is that of the destructive power of breakers, and those who have witnessed a breach made in such a harbour during a heavy gale of wind, are not likely to remain unimpressed with the importance of breakers in the removal of land.*

Slight attention to the manner in which waves break on a coast will soon show that, upon the prevalent winds and the proportion of those which force the greatest waves, or *seas*, as they are generally termed, on shore, will depend, other things being equal, the greatest amount of destructive action. Thus, on a coast on which western winds prevail, and there is sufficient extent of open sea before it, we should expect to discover the greatest loss of land, the force of the breakers being there the greatest and most incessant. As a whole, the coasts of the British Islands are exposed to the heaviest and most incessant breakers from winds ranging from the N.W. to the S.W., and but slight acquaintance with our coasts will soon satisfy the geologist, that if the other coasts of our islands were exposed to an equal amount of abrading force, a large portion of them would soon be cut away at a far more rapid rate than at present.

With regard to the force of breakers on the coasts of the British Islands, Mr. Stevenson has found by experiments at the Bell Rock and Skerryvore lighthouses,† that while the force of the breakers on the side of the German Ocean may be taken at about a ton and a half upon every square foot of surface exposed to them the Atlantic breakers fall with about double that weight, or three tons to the square foot. Thus a surface of only two square yards would sustain a blow from a heavy Atlantic breaker equal to about fifty-four tons.

Taking an equal amount of prevalent winds and of open sea over which they may range, it will soon be observable that the abrasion

* During a heavy gale in November, 1824, and also in another at the commencement of 1829, blocks of limestone and granite, from two to five tons in weight, were washed about at the breakwater, Plymouth, like pebbles. About 300 tons of such blocks were borne a distance of 200 feet, and up the inclined plane of the breakwater. They were thrown over it, and scattered in various directions. In one place a block of limestone, seven tons in weight, was washed a distance of 150 feet. We have seen blocks of two or three tons, torn away by a single blow of a breaker and hurled over into a harbour, and one of one and a half or two tons, strongly trenailed down upon a jetty, torn away and tossed upwards by the force of another.

† Proceedings of the British Association for the Advancement of Science, Edinburgh, 1850.

of rocks, of equal hardness and similar position, is modified according as the adjoining seas are tidal or tideless. In the latter case, though no doubt the pressure of the wind upon water raises it to levels above those which it commonly occupies, the difference is not so considerable as to bring any large faces of cliff exposed to the action of the breakers. A beach, moreover, piled in front of a cliff is, in such seas, as rarely passed and the cliff attacked. In tidal seas, on the contrary, many feet are vertically exposed to the fury of the breakers as the tide rises and falls; and beaches piled up in moderate weather are, in fitting situations, removed by the return action of the breakers, so that the cliffs are again open to abrasion. Moreover, the rocks are exposed to greater decomposition from being alternately wet and dry, a consideration of some importance in many climates, particularly in those where the temperature falls below the freezing point of water during certain seasons of the year. It should not, nevertheless, be forgotten that coasts, where breakers reach the cliffs at high water, are frequently protected by beaches at low water; and that, therefore, they are moved from the abrading power of the waves during all the time that they fall on the protecting beaches—a time which changes with the varying state of the tides and of the weather generally.

Attention will not long have been given to the abrading action of breakers on coasts before it will be seen that there are many circumstances modifying the effects which would be otherwise produced. It will be observed that the wearing away of coasts is, among the softer rocks more especially, often much accelerated by land-springs, which, as it were, shove portions of the cliffs into the power of the breakers by so moistening particular beds or portions of them, that much of the cliff loses its cohesion, and is launched seaward. The loss thus sustained in some coasts is very considerable.

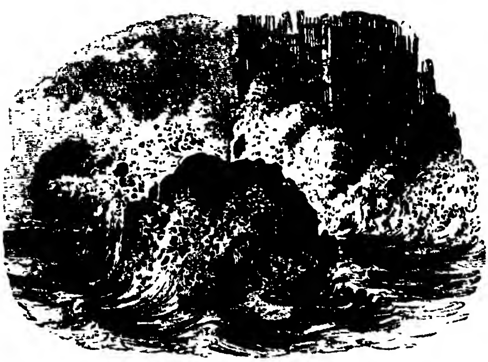
Fig. 40.

So far from being thus brought by, so to speak, inland influences within the reach of the sea, in other situations we find the higher parts of cliffs protruding over the sea beneath, as in the previous sketch (fig. 40), when we suppose the parts of the rock to be so coherent that the breakers have been enabled to excavate the lower part of the cliff in the manner here represented. The same action continuing, a time must come when the weight of the overhanging portion will outbalance the cohesion of the rock, and the mass above will fall. Breakwater, as it then becomes to a part of the cliff, much will depend as to the length of time it may so act, according to the manner in which it has fallen, particularly if stratified. If composed of beds of rock, and the slope of these beds face the sea, as in the following sketch (fig. 41), the breakers will have less power

Fig. 41.

to act upon them, than if the edges of the strata were presented to the sea, as represented beneath (fig. 42), in which position they offer the least resistance to the destructive action of the sea.

Fig. 42.



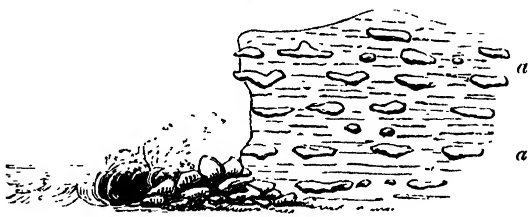
It will be sometimes found, that a hard rock constitutes the high

part of a cliff, while the lower portion is composed of a softer substance, such as a clay or marl, and that masses of the harder rock falling from above afford protection, for a time, to the lower part of the cliff. Thus, let *a* in the annexed section (fig. 43) re-

Fig. 43.

present the upper portion of a cliff formed of hard beds of rock, such as sandstone, while *b* is a marl or clay, then the action of the sea, *d*, upon the cliff would undermine it, and cause the fall of masses of the hard rock, *c*, which, accumulating at its base, would tend to protect it according to the quantity of fallen rock, the size of the masses, and their hardness. It will be found that cliffs composed as a whole of somewhat soft rocks, and clays, marls, or slightly indurated sandstones, are often protected at their bases by an accumulation of indurated portions of these rocks. Thus let the accompanying section (fig. 44) represent a clay in which there are

Fig. 44.

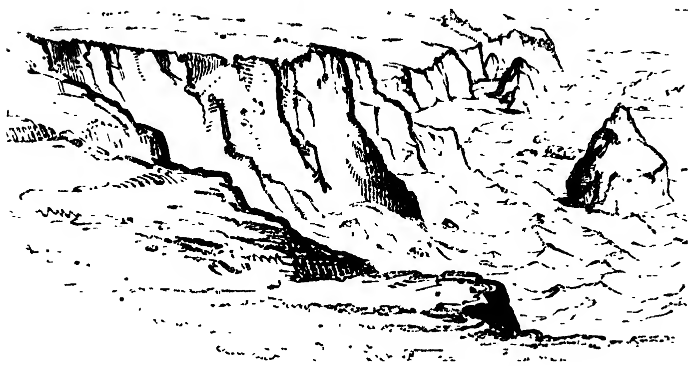


nodules of argillaceous limestones, as *a a* (and those of septaria in clays are often large), which, when washed out by removal of the clay, accumulate on the beach *b*. These then tend to protect the base of the cliff from the destructive action of the breakers. The study of any extended line of coast composed of horizontal or slightly-inclined beds of rocks of unequal hardness will present abundant examples of the modified protection afforded to the base of cliffs from the accumulation of masses derived from them.

Striking examples are often to be found on our shores of the wearing away of the land by the action of the breakers, so that rocks stand out in the sea detached from the main body of the land, but which once evidently formed part of it. Perhaps the

accompanying sketch (fig. 45) of the cliffs near Bedruthan, Cornwall, may afford an idea of the manner in which some of our coasts are thus cut back by breakers. The islets here represented have been formed by such an abrasion of the rocks to the present cliffs

Fig. 45.



of the mainland, that portions, somewhat harder, and better resisting the action of the breakers than the rest, have remained. The breakers not unfrequently work round portions of the cliffs, forming a cave through a projecting point or headland. This, from the continuance of the same destructive action, becoming gradually enlarged, the roof, from the want of support, falls, and the point becomes an island, round which the breakers work their way, gradually increasing the distance between it and the mainland.

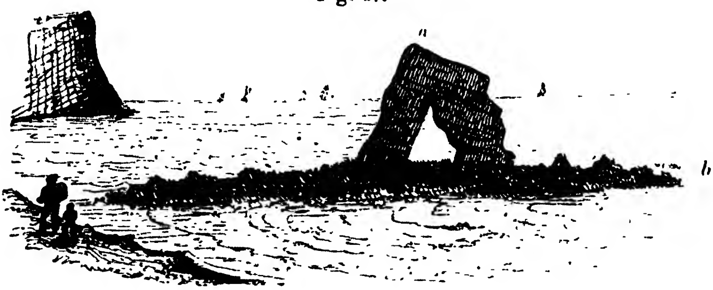
As might be expected, amid the wearing away of coasts by breakers, innumerable instances present themselves of unequal action on the harder and softer substances, according to their exposure to the destructive power employed upon them, so that long channels and creeks, and coves of every variety of form, are worked away in some situations, while hard rocks protrude in others.

Fig. 46.

Coves afford shelter to the fisherman, from being hollowed out in some localities, while the hard ledges act as natural piers in others. The previous sketch (fig. 46), of Polventon Cove, on the east of Trevose Head, Cornwall, may be taken as a fair illustration of a harbour scooped out by the action of the breakers, which have so worn away the slate *a*, from a line of hard greenstone, *b*, that the latter forms a natural pier, named the Merope Rocks, affording shelter from the north-west winds, which, when strong, are much to be dreaded on this coast.*

It is not often, however, we should expect, though it must sometimes occur, that a mere trace of beds, superincumbent upon dissimilar rocks, can be found on coasts, showing how such may be entirely removed from the subjacent rocks by the action of the breakers. In this respect, the annexed sketch (fig. 47), may be

Fig. 47.



useful. It represents a small patch *a*, of a conglomerate of the new red sandstone series, named the Thurlestone Rock (in Bigbury Bay, South Devon), reposing, with a moderate dip seaward, unconformably upon the edges of Devonian slates *b*. Here the breakers have almost entirely removed the red conglomerate which was deposited upon the slates, and, no doubt, once covered them far more extensively than is now observable.

In estimating the abrading power of breakers on an extensive line of coast, it is desirable not only to direct attention to the relative hardness of the rocks of which it is composed, but also to the position of the beds (if the rocks be stratified), and to the planes of slaty cleavage and of joints. It will soon be apparent that among stratified rocks, lines of coast, under otherwise equal circumstances, depend on the directions and dip of the beds. Their position relatively to the force of the breakers is necessarily important; for if a series of beds, such as those in the accompanying

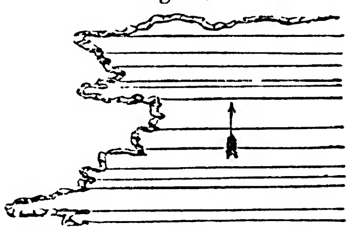
* Polventon Cove was at one time well known as a smuggling station, and is now often visited by vessels waiting for the tide into Padstow Harbour, a few miles distant.

sketch (fig. 48), dip seaward, the action of breakers falling on them in the manner represented would be comparatively trifling, since

Fig. 48.

the return of one breaker down the seaward slope of the beds, diminishes the force of the next falling upon it, and the power of the remainder, rushing up the slope, is gradually expended, and meets with no direct obstacle upon which it can destructively act. The positions in which the edges of the beds of any given rock are exposed to the action of the sea, are those where the abrading power of the breakers is most successfully exerted. Let us suppose that the annexed plan (fig 49) represents a line of coast exposed to the

Fig. 49.



north and west, and that the abrading action of the breakers is equal from both points; then the effects produced will depend upon the resisting powers of the rocks themselves. Taking the country to be composed of beds of slates and sandstones, having a strike or direction from east to west, and a dip about 45° to the north; then, supposing no cleavage planes, and the slates to be parallel with the sandstone beds, the resisting powers of the rocks would be greatest on the northern coast, since the beds would there all slope seaward, while the same rocks would be liable to much abrasion on the west, the edges of the beds being exposed in that direction. Numerous indentations would be the result, similar to those represented in the plan, the softest beds being worn into the deepest coves, and the harder constituting the most prominent headlands.

In all investigations as to the loss of land from the action of the sea upon it, dependence can rarely be placed on old maps of coasts, which are for most part very inaccurate; indeed, there would be no difficulty in producing those which would, when compared with a good modern survey, apparently show an increase of half or three-quarters of a mile on a cliff coast, where, in fact, there had been considerable loss.

We have seen that cliffs become abraded by the action of the breakers, sometimes alone, at others combined with that of the atmosphere and of land-springs. The mineral matter so brought within the influence of the sea has to be removed, and observation soon shows, that while one part of it is caught up in mechanical suspension, and is then liable to be carried away by the movements of tides or currents, another portion remains and is exposed to the grinding action of the breakers on the coast. This latter portion necessarily varies in size from the block, which can only be shaken by the blows of heavy breakers discharged upon it, acting with their greatest power, to the small pebble temporarily caught up in mechanical suspension, even by minor breakers, but which again sinks to the bottom when not exposed to their influence.

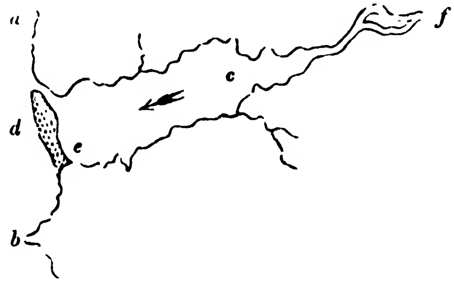
It will be observed, respecting shingle beaches, that during a heavy on-shore gale, every breaker is more or less charged with the materials composing the beach, and that the shingles are forced forward as far as the broken wave can reach, their shock against the beach driving others before them, not held in temporary mechanical suspension. Shingles are thus projected on the land beyond the reach of the retiring waves, and there accumulate in long ridges parallel to the coast, especially where the land is low behind the shingle beach. Heavy on-shore gales and high tides combined necessarily produce the greatest accumulation of shingle in such localities, and although occasionally a breach may now and then be formed at such times, it becomes speedily filled up by the piling action of the breakers.

Attention to a shingle beach will soon show, notwithstanding the minor removal of portions from one place to another, backwards and forwards, and the modifications arising from the obliteration of the little lines of beach, not unfrequently produced during moderate weather, that as a whole it travels in the direction of the prevalent breakers until arrested against some projecting portion of the coast. This must happen, if any force act upon the shingles more in one direction than another, since they would be compelled to travel in conformity with it; and observation proves that such is the fact,

for not only do we find pebbles of known rocks thus moved from the particular portion of cliff whence they have been derived, but, also, though breakers appear to adjust themselves to the tortuous character or outline of a coast, that there is always a slight oblique action in consequence of the main direction of the wind at the time.

One of the simplest forms in which the shingles of a beach are seen to have travelled is where, as in the annexed plan (fig. 50), we

Fig. 50.



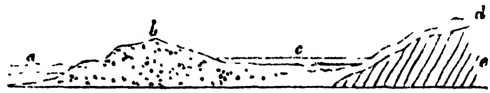
find a spit of shingle beach, *d*, composed of pebbles evidently derived from a coast, *b*, stretching in the direction to which the prevalent winds blow, the shingle beach being unable to cross over to the opposite coast (*a*) in consequence of the flow and ebb of the tide in and out of an estuary (*e*, *c*), into which a river (*f*) discharges itself at the higher end. In such cases, and they are to be seen in many situations, the rush of water is able to keep the channel open between the spit of beach *d* and the coast, *a*, not on the side of the prevalent winds, the ebb tide, especially when the river is in flood, effectually keeping the passage clear, and throwing off the shingle, which strives to cross over and block up the estuary.

There are good examples on the coast of Devonshire, at Teignmouth and Exmouth, of tongues of beach thus formed, but trending in different directions, exposure to the prevalent breakers being clearly seen to be the cause of the opposite directions taken by the beaches. At Teignmouth, a small portion only of the beach is derived from the rocks on the southward, and the river mouth is protected from the southerly and south-west winds, but exposed to the eastward and north-east. Hence, the beach is driven to the southward, and the river keeps its channel open by escaping against the hard cliffs of the Ness Point. The reverse of this action is observed at Exmouth.

We have various examples on our coasts (the Looe Pool, near Helston, Cornwall, and Slapton Pool, in Start Bay, Devon, are illustrative instances), where the river waters being insufficient

to contend with the beach-piling action of the breakers, the outlet for the fresh waters is completely crossed by beaches, and lakes are formed behind them, the surplus waters percolating through the shingles. From this state of things to the escape of a river, by passing close to a hard cliff, there is every modification. In many localities exposed to open sea, the minor streams will be found dammed up by, or cutting through beaches, according to the state of the weather. A heavy on-shore gale throws up a bar of beach, which a flood from the land removes, and so the conditions alternate, with every kind of modification. The following (fig. 51) is a sec-

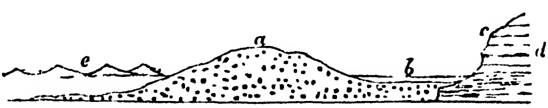
Fig. 51.



tion through the beach and lake at Slapton Sands, Start Bay, *a*, being the sea, which throws up the beach *b*; *c*, the freshwater lake behind the beach; *d*, the weathered and decomposed portion of the slate rocks *e*. This section is interesting also from showing that, at the present relative levels of sea and land in that locality, the sea has not acted on the hill *d e*, since the loose incoherent substance of *d* would have been readily removed by the breakers.

The Chesil Bank, on the coast of Dorsetshire, affords a good example of the driving forwards of shingle in a particular direction by breakers, produced by the action of prevalent winds. It is about 16 miles long, connecting the island of Portland with the mainland, and for about eight miles from that island, is backed by a narrow belt of tidal water, known as the Fleet. From its position, the heavy swells and seas from the Atlantic, often break furiously on this bank, which protects land that would otherwise soon be removed by them. The following (fig. 52) is a section

Fig. 52.

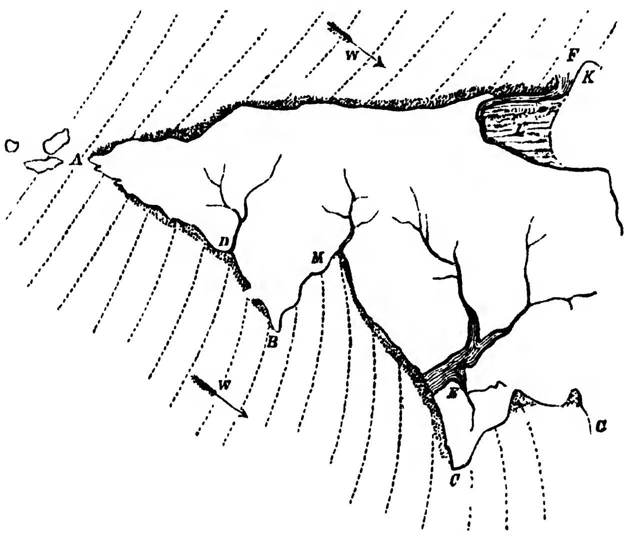


across the Chesil Bank, *a* being the bank; *b*, the water termed the Fleet; *c*, small cliffs formed by the waves of the Fleet, and by falls from the effects of land springs; *d*, various rocks of the oolite group, protected from removal by the Chesil Bank, and *e*, the sea, open to the Atlantic. In this case also we seem to have an example of the Atlantic breakers not having reached the land behind since the relative levels of the sea and land were such as we now find them.

A gradual sinking of the coast would appear to afford an explanation of the phenomena observed, and is a supposition harmonizing with the facts previously noticed at Slapton Sands.

The general travelling of shingles on a coast, much modified by conditions, may be illustrated by the following plan (fig. 53), in

Fig. 53.

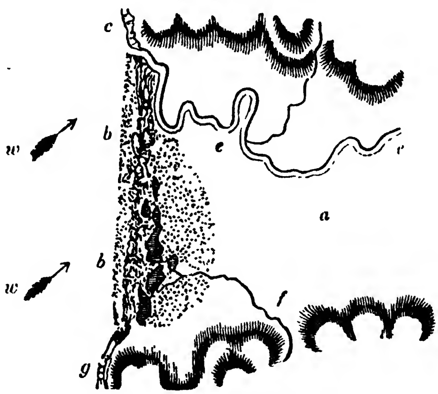


which G, C, B, A, and F, represent a line of coast exposed to the prevalent winds W. W. The lines of waves are shown by dotted lines, made to curve inwards behind protecting headlands. In consequence of the configuration of the coast, and its chief exposure to the action of breakers, the shingle would tend to travel from A to F on the one side, and from A to G on the other. There would be little impediment to their course along the line A F, until the river, on the right, presented itself, where K represents a cliff of hard rock, and F, the tongue of drifted beach, arising from the conditions previously noticed (p. 55). Between A and G the effects would be different, particularly if it be assumed that the point of land B projects into deep water. Considering the river at D as small, the beach would traverse its mouth and be only removed during heavy floods, so that the mass of shingle would tend to travel towards the point B, and there descend and accumulate in deep water. Supposing C another point of land jutting into deep water, it would bar the further progress of the shingle travelling from M to it, a beach closing the outlet of the lake at E, assumed

to be shallow, and under the conditions previously mentioned as existing at the Looe Pool and Slapton, the back fresh-waters being unable to force outwards the beach accumulated by the breakers.

At L (fig. 53), we have shown a marsh accumulation behind the protecting influence of the shingle beach F, this accumulation being a deposit from the checked waters of the river, by the action of the flood-tide, when rains had caused detritus to be borne down in mechanical suspension by the river. The annexed plan (fig. 54) may aid in showing the modification often observable where the tongue of beach is composed of sand, backed by sand-hills: *a* repre-

Fig. 54.



sents a tract of low level land, which may either have been formed by the filling up of an estuary under existing conditions, or be the bottom of an estuary of a previous time, now raised; *b*, *b* a sandy beach and sand-hills, protecting the low land from the ravages of the sea; and *e*, *e*, a river which makes good its course to the sea, by keeping close to the hard cliff *c*. We have also assumed that a small stream, such as *f*, occurs, so that it does not find its way to the main stream, but loses itself in pools amid the sand-hills, the mud from it tending to consolidate and cement the blown sands, binding them together, and hence supporting a vegetation which would not otherwise have found the conditions for its growth.

In these situations there is often a severe struggle between the action of the sea (swept by prevalent winds *w*, *w* (fig. 54), piling sand upon the beach *b*, *b*), assisted by that of the wind on the sand-hills, and the waters of the river. The effect of such a little stream as *f* is not unfrequently to give much firmness to the end of the beach and sand-hills towards *g*, while the sand blown over towards the main river is caught up by it and again carried out to sea, particularly during floods.

Let us now consider sandy beaches and sand-hills, bordering coasts generally. The sand on sea-shores is derived from the rivers bearing it down in mechanical suspension, or forcing it forward on the bottom to the sea; from the wearing away of cliffs of sand and sandstone by breakers, or from the attrition of the pebbles or shingles on beaches, so that finally they become mere sand. To these causes must, in certain localities, be added the trituration of shells and corals, ejected from the sea and piled up as beaches, in some places by themselves, at others variously mingled with ordinary sand.

Regarding the common occurrence of sea-shore sand of a certain average degree of fineness, it should be observed, that as detritus approaches that size it becomes more and more difficult to reduce it further, since it is then more and more easily caught up in mechanical suspension by breakers, and therefore grain cannot so readily be ground against grain.

The accumulation of sand-hills can as readily be studied on various portions of our own coasts, as in those parts of the world where the shores present little else than sandy dunes for hundreds of miles. A low line of coast with a shallow sea outside, and presenting a fair exposure to breakers, is usually sufficient for their production. The greater amount of shore dry at low water in tidal seas, and the greater the exposure to prevalent winds, the larger is commonly the accumulation of the sand-hills, other conditions being equal. The cause is sufficiently obvious. A large tract of sand, exposed between high and low water mark, and under the influence of a strong on-shore wind, is soon partially dried on its surface, and the dried sand is swept inland beyond the reach of the breakers of the rising tide, which could have again caught up this sand in mechanical suspension and have distributed it.

It is desirable, that the observer should select some day, when a strong on-shore wind blows over a tract of sand, and the drier the state of the atmosphere the better, to see the manner in which the grains of sand are transported inland, and to mark the various modifications of surface which arise from the deposit of the sand among the sea-weeds, or pebbles, should any occur. He will find that, while some grains of sand may be held in mechanical suspension by the wind at a height of an inch or so from the sandy surface beneath, the friction of the air on the latter produces such retardation of the wind current, that similar grains of sand are merely swept along the bottom. In such respects this perfectly accords with the movements of detritus in river channels, and

above noticed. The difference is merely that the transporting power is air in the one case, and water in the other. Indeed, this action is so completely of the same kind, that the furrows and ridges produced by the friction of water currents over arenaceous accumulations, may be advantageously studied where wind currents drive over sand.

To observe the manner in which the sands furrow and ridge, and move onwards, a time should be chosen when the wind is not sufficiently powerful to hold the sand in mechanical suspension, but merely to drive or push it onwards. The ridging, as shown in the annexed section (fig. 55), is accomplished by the driving of

Fig. 55.

the grains with sufficient force by the wind acting in the direction *w*, *w*, merely to carry onwards those on the surface, the retardation of which by friction on those beneath so acts that the grains at *b*¹ are driven on to the ridge *a*¹, and by accumulation (the power of the wind being sufficient to cut down the ridges to a kind of general level, or curve, as the case may happen to be) fall over into the furrow *b*², and so on with the ridges *a*² and *a*³. As the friction is continued, the crests of the ridges advance, and their places are occupied by furrows, to be replaced by ridges. When the velocity of the wind is favourable for researches of this kind, an observer will best see the advance of the ridges, by placing himself amid the moving surface, and directing his attention to the ridges nearest him, at the same time making due allowance for the obstacles presented by his feet, which will produce modifying influences, readily appreciated.

Arrived at the margin of the shore line, the sands pushed forward in the manner noticed, or caught up in mechanical suspension, when the winds are sufficiently powerful, accumulate, forming ranges of sand-hills, in some countries characteristic of long lines of coast. By their accumulation and tendency to move inland, in the direction of the prevalent and more powerful winds, they produce changes upon the adjoining low lands, and even upon considerable slopes of adjoining hills. The sands accumulated in the Bay of Biscay, may be considered as affording an illustrated instance of this encroachment on the land, and the modifications thence pro-

duced, inasmuch as great changes are known to have been there effected during the historical period.

The advance of these dunes is described as irresistible, and at a rate of 60 and 72 feet per annum. They force before them lakes of fresh water, formed by the rains, which cannot find a passage into the sea in the shape of streams. Forests, cultivated lands, and houses disappear beneath them. Many villages noticed in the middle ages have been covered, and a few years since it was stated, that in the department of the Landes alone, ten villages were threatened with destruction. "One of these villages, named Mimisan, has been," said Cuvier, "striving for 20 years against them; and one sand-hill, more than 60 feet high, may be said to be seen advancing. In 1802, the lakes invaded five fine farms belonging to St. Julien; they have since covered a Roman causeway, which led from Bordeaux to Bayonne, and which was seen about 40 years since, when the waters were low. The Adour, which was once known to flow by Vieux Boucaut, and to fall into the sea at Cape Breton, is now turned aside more than a thousand toises."*

There are few extended lines of coast which will not afford opportunities for the observation of sand-hills, and their mode of accumulation and change, for strong winds acting upon even a comparatively exposed surface, soon produce a marked alteration of their form. Successive accumulations, shown by the remains of surface vegetation grown during times where it could partially establish itself, are cut away and heaped up into other hillocks, new matter derived from the sea being added to the general mass. At times, a strong off-shore wind forces sand back to the sea, acting not only on the sand-hills over which it blows, but also on the dried surface of the sands bared between high and low tide, these still more easily carried seaward when left dry for a longer time, between the highest lines of neap and spring tides.

As the sand commonly found in sand-hills is not usually borne high in mechanical suspension by the winds, such districts will not long have engaged attention before the power of running water, even of small streams, if their courses be unobstructed and fairly rapid, will be seen to prevent the extension of blown sands. The sand drifted, falling into the streams, is carried onwards by these waters, and is thus prevented from traversing them.† Sand-

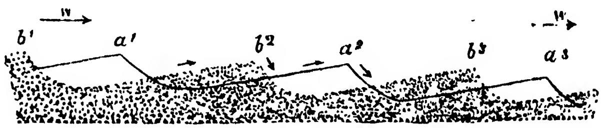
* Cuvier, *Dis. sur les Revolutions du Globe.* A thousand toises is about 6,400 English feet, or somewhat less than a mile and one quarter.

† Good examples of this fact may be observed on the coast of Cornwall. The Perran Sands are thus bounded for nearly two miles between Treamble and Holy

above noticed. The difference is merely that the transporting power is air in the one case, and water in the other. Indeed, this action is so completely of the same kind, that the furrows and ridges produced by the friction of water currents over arenaceous accumulations, may be advantageously studied where wind currents drive over sand.

To observe the manner in which the sands furrow and ridge, and move onwards, a time should be chosen when the wind is not sufficiently powerful to hold the sand in mechanical suspension, but merely to drive or push it onwards. The ridging, as shown in the annexed section (fig. 55), is accomplished by the driving of

Fig. 55.



the grains with sufficient force by the wind acting in the direction *w*, *w*, merely to carry onwards those on the surface, the retardation of which by friction on those beneath so acts that the grains at b^1 are driven on to the ridge a^1, and by accumulation (the power of the wind being sufficient to cut down the ridges to a kind of general level, or curve, as the case may happen to be) fall over into the furrow b^2, and so on with the ridges a^2 and a^3. As the friction is continued, the crests of the ridges advance, and their places are occupied by furrows, to be replaced by ridges. When the velocity of the wind is favourable for researches of this kind, an observer will best see the advance of the ridges, by placing himself amid the moving surface, and directing his attention to the ridges nearest him, at the same time making due allowance for the obstacles presented by his feet, which will produce modifying influences, readily appreciated.

Arrived at the margin of the shore line, the sands pushed forward in the manner noticed, or caught up in mechanical suspension, when the winds are sufficiently powerful, accumulate, forming ranges of sand-hills, in some countries characteristic of long lines of coast. By their accumulation and tendency to move inland, in the direction of the prevalent and more powerful winds, they produce changes upon the adjoining low lands, and even upon considerable slopes of adjoining hills. The sands accumulated in the Bay of Biscay, may be considered as affording an illustrated instance of this encroachment on the land, and the modifications thence pro-

duced, inasmuch as great changes are known to have been there effected during the historical period.

The advance of these dunes is described as irresistible, and at a rate of 60 and 72 feet per annum. They force before them lakes of fresh water, formed by the rains, which cannot find a passage into the sea in the shape of streams. Forests, cultivated lands, and houses disappear beneath them. Many villages noticed in the middle ages have been covered, and a few years since it was stated, that in the department of the Landes alone, ten villages were threatened with destruction. "One of these villages, named Mimisan, has been," said Cuvier, "striving for 20 years against them; and one sand-hill, more than 60 feet high, may be said to be seen advancing. In 1802, the lakes invaded five fine farms belonging to St. Julien; they have since covered a Roman causeway, which led from Bordeaux to Bayonne, and which was seen about 40 years since, when the waters were low. The Adour, which was once known to flow by Vieux Boucaut, and to fall into the sea at Cape Breton, is now turned aside more than a thousand toises."*

There are few extended lines of coast which will not afford opportunities for the observation of sand-hills, and their mode of accumulation and change, for strong winds acting upon even a comparatively exposed surface, soon produce a marked alteration of their form. Successive accumulations, shown by the remains of surface vegetation grown during times where it could partially establish itself, are cut away and heaped up into other hillocks, new matter derived from the sea being added to the general mass. At times, a strong off-shore wind forces sand back to the sea, acting not only on the sand-hills over which it blows, but also on the dried surface of the sands bared between high and low tide, these still more easily carried seaward when left dry for a longer time, between the highest lines of neap and spring tides.

As the sand commonly found in sand-hills is not usually borne high in mechanical suspension by the winds, such districts will not long have engaged attention before the power of running water, even of small streams, if their courses be unobstructed and fairly rapid, will be seen to prevent the extension of blown sands. The sand drifted, falling into the streams, is carried onwards by these waters, and is thus prevented from traversing them.† Sand-

* Cuvier, *Dis. sur les Revolutions du Globe*. A thousand toises is about 6,400 English feet, or somewhat less than a mile and one quarter.

† Good examples of this fact may be observed on the coast of Cornwall. The Perran Sands are thus bounded for nearly two miles between Treamble and Holy

drifts are sometimes also found stopped by the flow of tidal waters in and out of lagoons. Of this kind, the accumulation of sand at the northern side of a spit of land, terminated by sand-hills, near Tramore, on the eastern coast of Ireland, may be considered as a good example.

As having a geological bearing, the observer would do well to direct his attention to the manner in which the remains of vegetable and animal life, both terrestrial and marine, become mingled in sand-hills. Portions of seaweeds will frequently be found blown, when dry, amid the terrestrial vegetation of the sand-hills; and the shells of the helices, which are often found in multitudes in such situations get mingled with marine shells, or their fragments.

In some situations, the sand-hills are largely composed of comminuted shells, ground to that state by the breakers; and in such cases, consolidation of parts of them may be observable, having the hardness of many sandstones. The carbonate of lime of the shells becomes acted upon by the carbonic acid in the rain waters, with additions from decomposing vegetation, when plants have established themselves on the surface of the sand, and a final deposit of the carbonate of lime, thus held in solution, agglutinates the grains of sand together. Indurated sands of this kind are sufficiently hard, occasionally, to be employed for building purposes.*

Well Bay. Much land is stated to have been covered by drifts from the Perran Sands, in consequence of a small stream having been covered by mining operations near Gear.

* The consolidated calcareous sand of New Quay, Cornwall, has been long used as a building stone. Not only is the neighbouring church of Crantoch built of this modern sandstone, but very ancient stone coffins have also been discovered, composed of the same consolidated sand, in the adjoining churchyard. The grains are so firmly cemented in this New Quay sandstone, that where it graduates into a kind of conglomerate, pebbles of quartz and hard sandstone are generally broken through by a blow on the compound rock.

CHAPTER V.

DISTRIBUTION AND DEPOSIT OF SEDIMENT IN TIDELESS SEAS.—DEPOSITS OF THE NILE.—OF THE PO AND RHONE.—CONTEMPORANEOUS DEPOSITS OF GRAVEL, SAND, AND MUD.—DEPOSIT OF VOLCANIC ASHES AND LAPILLI.—DEPOSITS IN THE BLACK SEA AND THE BALTIC.—GULF OF MEXICO AND MISSISSIPPI.

As tideless seas might be considered as mere salt-water lakes, the distribution and deposit of detritus in them would, as a whole, resemble that of fresh-water lakes, particularly of those attaining the magnitude of the great North American lakes, but for the difference in the relative specific gravities of their waters. Slight attention to the overflow of rivers swollen by rains, and charged with mechanically-suspended matter, into the sea, will show that the discoloured waters of the rivers, instead of falling beneath the waters into which they flow, as is seen at the higher part of the lake of Geneva, and numerous other lakes, proceed seawards on the surface of the sea waters, and often to considerable distances. The cause is simply that, though discoloured by the detrital matter held in mechanical suspension, these river waters are still specifically lighter than the sea waters into which they flow.

The distances to which the river waters sometimes flow seaward, transporting fine detrital matter, parting with it gradually, must, when the great rivers of the world become full and turbid, be often very considerable. Colonel Sabine has stated, that at three hundred miles distant from the mouth of the Amazons, discoloured water, supposed to come from that river, was found, with a specific gravity of 1·0204, floating above the sea water, of which the specific gravity was 1·0262, the depth of the lighter water being estimated at 126 feet. It would be well that observers should direct their attention to such facts, for their accumulation would tend much to show us the extent to which fine sedimentary matter may be thus borne beyond the action of tides and coast

currents.* As much matter may be thus distributed in chemical solution, valuable information might also be collected as to the kind and quantity of substances so held in solution.

From the varied depths near its shores, the Mediterranean affords us a good example of the deposits effected in seas which are commonly termed tideless. The great rivers which discharge themselves into it, such as the Nile, Po, and Rhone, now transport little sedimentary matter that is not finely comminuted, and of easy mechanical suspension. The Nile, which has been estimated to deliver a body of water annually into the Mediterranean about 350 times that which flows out of the Thames, beginning to rise in June, attaining its maximum height in August, and then falling until the next May, must thrust forward, from its periodical rise and fall, fine sedimentary matter with great regularity, tending thus to produce consecutive layers or beds of mud and clay of considerable uniform thickness and character, in those situations where modifying conditions do not interfere. Part of the fine matter brought down from the interior in mechanical suspension is deposited on the lower grounds traversed by the Nile; and it has been calculated that the surface of Upper Egypt has, in this manner, been raised more than six feet since the commencement of the Christian era. The fine matter not so deposited, passing with the river waters seaward, is necessarily borne furthest outwards when the greatest force of the river water prevails, namely, in August of each year.

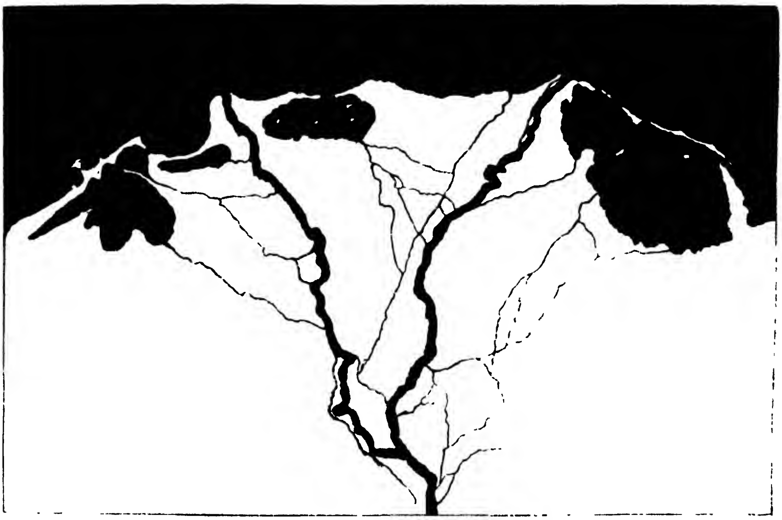
The matter thus borne seaward may be kept a greater or less time mechanically suspended, according to the agitation of the surface by winds, but, as a whole, there must be an average area over which it is thrown down; the greatest distance of the deposit from the mouths of the Nile being attained in August, though the greatest thickness of a year's deposit will be nearer the land. As the river mouths advance, these sheets of fine sediment would be expected to extend further seaward, overlapping each other.

Where the surface of the sea cuts the slightly-inclined plane of sedimentary matter, partly in the sea, and partly on the land, the

* Very little practice would enable those who may have opportunities of making such observations to ascertain the amount of matter mechanically suspended in waters of this kind. If the scales be not very delicate, by pouring a large volume of the water through a filter, previously weighed, such an approximation to the truth may be obtained as might be useful. As previously observed (p. 28), mere evaporation of the water would give not only the matter in mechanical suspension, but that also in chemical solution

breakers separate the finer from the coarser substances, keeping the former easily in mechanical suspension, and removing them from the shore outwards. The result is, an arenaceous boundary, with banks so formed as to include lagoons, such as are seen in the accompanying sketch of the delta of the Nile (fig. 56), at Lakes Mareotis, Bourlos, and Menzaleh.

Fig. 56.



These lakes gradually fill up, the shore advances, and so, even supposing the same relative level of sea and land not to be altered through a long succession of ages, the bed of the Mediterranean becomes more shallow in that region, and a mass of matter, such, for the most part, as would eventually form clay, is accumulated; the upper portion sandy from the action of the breakers upon the level of the sea, and from the sifting action, so to speak, of the waves further seaward, at depths where that influence could be felt.

From the periodical character of the rise of water in the Nile, the equivalent periodical deposits might even be marked by bands or layers extending to distances bearing a relation to the amount of transporting power of the river waters, so that coarser particles could be carried further and over more extended areas at one time than at another. The general deposit, however, gradually advancing seaward, successive annual accumulations would, as a whole, overlap each other.

When we regard the Po and Rhone, we have not the same very marked periodical rise of their waters; though no doubt, taken as

a whole, there may annually be times when more matter is borne outwards than at others. With the exception of the regularity of effects likely to be produced by the rise and fall of their waters, the accumulations formed by deposit from the detrital matter borne seaward by the Po and Rhone would, however, be similar to those of the Nile;* the same discharge of fresh waters holding matter in mechanical suspension over the surface of the sea, the same sifting of the detritus so borne seaward, where the action of the waves can reach it, and the same general order of accumulations.† As the general mass of matter advanced, there would be mud or clay formed at the greatest distance from the land, over which the sands, separated from the finer or mud-formed particles in the shallow water and along shore, would gradually be spread, mingled here and there with a patch of clay, or silt clay, deposited in the lagoons, behind lines of beach thrown up by the breakers.

These rivers are merely mentioned as marked examples. An inspection of a good chart of the Mediterranean will show that there are many others, the floods in which only bear mud and sands into it, the heavier detritus not reaching the shores, the fall of the river beds, and the force of their waters, being insufficient. In all such cases the accumulations would be mud or clay for a base, with an arenaceous top, so far as the causes we have noticed could prevail. It will be obvious, that clay may be accumulated in the depths seaward, while sands are advancing from the shore towards them, so that, if at any future geological period, the whole became uplifted above the level of the sea, we might have a sheet of arenaceous matter covering another of clay, the parts of each,

---

* As respects the Po, M. Prony considered himself authorised to conclude, from the examination of a large amount of evidence, " First, that at some ancient period, the precise date of which cannot now be ascertained, the waves of the Adriatic washed the shores of Adria. Secondly, that in the twelfth century, before a passage had been opened for the Po at Ficarrolo, on its left or northern bank, the shore had already been removed to the distance of 9,000 or 10,000 metres (5½ to 6 miles) from Adria. Thirdly, that the extremities of the promontories formed by the two principal branches of the Po, before the excavation of the Taglio di Porto Viro, had extended by the year 1600, or in 400 years, to a medium distance of 18,500 metres (about 11½ miles) beyond Adria; giving from the year 1200 an average yearly increase of the alluvial land of 25 metres (82 feet). Fourthly, that the extreme point of the present single promontory, formed by the alluvions of the existing branches, is advanced to between 32,000 to 33,000 metres (about 19¾ to 20½ miles) beyond Adria; whence the average yearly progress is about 70 metres (229½ feet) during the last 200 years, being a greatly more rapid proportion than in former times."—*Cuvier*, *Dis. sur les Rev. du Globe.* M. Morlot infers that the land round the head of the Adriatic is gradually sinking, but that the deposits of the rivers are still sufficient to effect a general gain upon the shores of that sea.

† It should be remarked that there are also calcareous accumulations at the mouth of the Rhone.

though continuous, formed at different times, and portions of the clay equivalent to parts of the sand. There would be zones, so to speak, of arenaceous matter corresponding with the advance of the coast, and not separated from the common sheet of that of which it constitutes a part, being formed at the same time with a layer of clay, which a prolongation of the sandy coating would cover at a subsequent period.

The same sea fortunately furnishes numerous examples of short rivers, with rapid falls of their beds, and occasional abundant supplies of water, thrusting pebbles into it. The effects produced are the same as when torrents discharge themselves into lakes, with the difference that the muddy part of the waters flows over the surface of the sea, the sand separating from it. According to the depth of water, and this is sometimes considerable, is the sand accumulated; if fairly deep, the sand falls not far distant from the coast, while the pebbles accumulate on the shore, and the embouchure of the river is extended. Though the general bed of shingles (the upper part acted upon by the breakers, as upon any other shingle beach) would advance as a whole, with an even upper surface, the accumulation of gravel or shingles would be formed by many irregular protrusions produced by changes in the direction of the river's mouth. The depth being favourable, we should expect, under such conditions, an accumulation of the following kind (fig. 57), *a a* being a section of the land, formed of beds of rocks

Fig. 57.

(represented as dipping inland, merely to separate them clearly from the other deposits), *b* the bed of the river, bearing down pebbles, sand, and mud into the sea, the level of which is shown by the horizontal line *e*; *d* exhibits the first accumulation of pebbles thrown over the steep shore, the pebbles falling to the bottom, and the sand only being deposited in a regular layer, more outwards; *c* the continuation of the sandy layer seaward; *f f* the mud deposited beyond the sand, and also continued; and *g* the extension of the pebbles over the sand, at some given time. In such an accumulation we should expect, after both sand and gravel had overspread the clay, a lower deposit of clay, above this anotehr of sand, and over the sand, gravel; parts of the gravel, sand, and

clay, notwithstanding the extension of each layer continuously in the manner stated, being equivalent to each other in age, for the reasons before assigned.

Where depths were less considerable, we should expect an intermixture of the gravel and sand in a more irregular manner, and with an arrangement depending on the action of the breakers upon them; this action tending to pile back the shingles, as a whole, while it permitted the sandy sediment to be caught up in mechanical suspension, and thus it might be carried outwards by the river waters, in places where the stream of these waters could be felt. As previously observed, the finer and mechanically suspended particles would be borne over the surface of the sea, according to the volume and velocity of the outpouring river waters, eventually forming a layer of mud or clay where deposited. It will be obvious, that as the volume and velocity of the river waters varied, so would be their power to carry outwards, beyond the influence of the breakers, mechanically-suspended matter of different volume and weight, and hence that, within a certain range, there might be mixed layers of sand, silt, or mud, according to circumstances.

Not only do the rivers thus contribute matter, borne down by them to the shores, to be there arranged by the breakers, or thrust out into the sea and deposited in it, but every river also bears down some matter in chemical solution, to be added to the solutions present in the seas. In tideless seas, each river sends down its solutions into water which may, to a great extent, be considered stagnant, notwithstanding certain movements or currents sometimes in it, so that at the embouchures of the rivers the substances so borne down prevail within distances to which the river waters may act. In many localities around the Mediterranean, the river waters transport large quantities of bicarbonate of lime in solution. While we may consider that much of this substance is consumed by fish, crustaceans, and molluscs, for their harder parts, there is probably a large surplus which eventually takes the form of calcareous accumulations beneath the sea. The rivers which transport bicarbonate of lime abundantly would, when in flood, probably also carry forward sedimentary matter, so that at the mouths of such rivers we might have alternate times, variable probably in duration, when the rivers were clear, and carried forward, as compared with the volume of water, a large proportion of bicarbonate of lime, and when this substance bore a far less proportion to the volume of water, while fine detritus was abundant. Under such conditions we should have alternately layers of mud and calcareous matter, or mud

more calcareous at one time than at another, so that eventually the calcareous matter might tend to separate into nodules, and in planes corresponding to the times when it was most abundantly thrown out of the rivers. In like manner we might have sulphate of lime, commonly enough in solution in some rivers, mingled with the mud, and eventually crystallizing out as selenite, a mineral so frequently discovered in various clay beds. Many other combinations of different substances, some in solution, others mechanically suspended, and borne down by the same rivers, will readily present themselves to the mind of the observer, and suggest attention to the conditions under which both are carried out into tideless seas.

When considering deposits in tideless seas, we must not forget those resulting from the fall of ashes and lapilli, thrown out from volcanos. The Mediterranean may fortunately be considered with reference to this kind of accumulation also, as there are volcanos in action in it, and on its shores. The great eruption in 79, which not only overwhelmed Herculaneum, but showered ashes in such profusion upon Pompeii as also to bury that town, could not fail to have thrown a large amount of ashes and lapilli into the sea; and considering the distances to which ashes are known to have travelled from volcanic vents, the ashes at least may have been widely spread. It will be obvious that whatever kinds of sedimentary accumulations they subsided upon through the sea, the ashes would mingle with them, coating over such deposits where tranquillity reigned, either from the depth of water or other causes, with a layer of ash. Where the action of waves on the bottom, or of breakers on the coasts, could be felt, in whatever tranquil state the ashes may have fallen originally to the bottom, they would be mixed up with the mud, sand, or pebbles, as the case might be, when thus acted upon, so that the particles of the ash would be disseminated among them. All rivers upon which the ashes fell would probably bear much of them outwards in mechanical suspension, for the fine matter which can be upborne and be carried by the winds to great distances would not readily subside through the river waters.

Under this view, the deeper parts of the Mediterranean, and especially those to which other sedimentary matter could not be carried by the movement of sea currents, or the drift of river waters outwards, would be those where the layers of ash would be most unmixed with other matter, excepting as regards the deposit of any substances from chemical solution in the sea, and to which its great tranquillity may be favourable. We do not know the depths at which calcareous accumulations may now be forming in

the Mediterranean, but whether in shallow or deep situations, any ashes falling upon them would either accumulate in layers, or be mingled up with the limestone, according to the rapidity with which the one may subside, or the calcareous matter be deposited.

Not only are there volcanos on the borders of this sea, of the magnitude of Etna and Vesuvius, throwing out ashes and lapilli, but we have had evidence in our times, so lately as 1831, of the uprise of a volcano through the sea,* between Pantellaria and the coast of Sicily, and from deep water.† Columns of black matter are described as being thrown out of the crater, to the height of three or four thousand feet, spreading out widely even to windward. The upper part, above the sea at least, seemed to have been solely composed of ashes, cinders, and fragments of stone, commonly small. Among these, fragments of limestone and dolomite, with one, several pounds in weight, of sandstone, were observed, appearing to show that the volcanic forces had broken them off beds of these kinds of rock, when the igneous matter had been propelled through them.

An island so constituted, could not long resist the destructive action of the breakers, and thus, as soon as the supply of ashes, cinders, and fragments of rock ceased, it was cut away by them, and reduced to a shoal. During the time that this volcanic mass was accumulating, a large amount of ashes and cinders must have been mingled with the adjacent sea before it reached its surface, and no slight amount would be distributed around, when ashes and cinders could be vomited into the air. Add to this the quantity caught up in mechanical suspension by the breakers, and there would be no small amount to be accumulated over any deposits forming, or formed on the bottom around this locality, and out of the reach of any lava currents which might have flowed beneath the level of the sea. The breakers while they removed the lighter substances would, as it were, so sift the whole, that the heavier fragments would gradually subside to lower levels, and eventually beneath the action of seas breaking above, or simply moving the bottom during very heavy weather. Finally, there would be a

* To the island thus formed the various names of Sciacca, Julia, Hotham, Graham, and Corrao were given. Dr. Davy, who visited this volcanic island on the 5th August, 1831, has given a detailed account of it in the Phil. Trans. for 1832. M. C. Prévost was charged by the Academy of Sciences of Paris to visit and report upon it. He reached the island on the 28th September of the same year. It was then about 2300 feet in circumference, with two elevations, from 100 to 200 feet high, on different sides of the crater, the latter filled with boiling water.

† Captain Smyth proved (Phil. Trans. 1832) that the volcano did not rise from the Adventure Bank, as was first supposed, but to the westward of it, and from deep water.

collection of fragments, cemented by ash and cinders, in which there would not only be pieces of igneous rocks, but of limestone, dolomite, and sandstone also, for we are not to suppose that the pieces found accidently on the surface were those alone thrown out of the crater.

Thus, then, in the Mediterranean a very complicated series of contemporaneous accumulations is now in progress, its uneven bottom* being variably covered, according to conditions, by the matter brought into it either in solution or mechanical suspension by rivers; eroded from its shores by the action of the breakers, or ejected by volcanos, the whole, excepting lava currents or large sudden accumulations of ashes and cinders, more or less mingled with the remains of organic life, these remains themselves sometimes sufficient to form long-continued layers or beds.

Though, for convenience, the Mediterranean has been treated as a tideless sea and without motion, this is not strictly correct, inasmuch as small tides are felt in it, and currents are found. Indeed, as respects the latter, when powerful winds, by their friction, force the surface waters in some given direction for the time, well seen when driven against any part of the boundary coasts,† the movement is then sufficient to carry any substances, mechanically suspended, to distances proportionate to the power and continuance of the winds. When these waters again come to a state of repose, the return action will be similar. There are also currents in the Mediterranean, such as that out of the Black Sea into it through the Sea of Marmora, and the current at the Straits of Gibraltar, which sets in from the Atlantic,‡ the latter modified, however, by the

---

* In considering the deposits now taking place in this sea, we should bear in mind that it is divided into chief basins (see Captain Smyth's charts) by a winding shoal, the Skerki, connecting Sicily with the coast of Africa. The run of soundings upon this shoal, proceeding from the African to the Sicilian coast, gives 34, 48, 50, 38, 74, 20, 70, 52, 91, 16, 15, 32, 7, 32, 48, 34, 54, 70, 72, 38, 55, and 13 fathoms, whence its inequalities may be seen. There are soundings in 140, 157, and 260 fathoms on either side, and places where bottom has not been reached with 190 and 230 fathoms of line.

† An observer may often have opportunities in the ports of the Mediterranean of seeing the rise or depression, as the case may be, of the sea, according as the winds at the time may be blowing with strength off or on shore. Canals frequently afford good opportunities of observing this kind of action of wind on water; for the canal levels, in still weather, being accurately known, it becomes easy to see how much these waters are raised or depressed as the winds may press them in one direction or another. Mr. Smeaton found that in a canal, four miles in length, the water was kept up four inches higher at one end than at the other, by the action of the wind along the canal. The Caspian Sea is several feet higher, at either end, according as a strong northerly or southerly wind may prevail.

‡ Both these currents have been attributed to the evaporation of the surface waters of the Mediterranean, that sea not receiving a sufficient equivalent from the discharge

tides as respects the African and European shores of the Straits.* The current from the Atlantic is described as setting eastward into the Mediterranean at the rate of about 11 miles in 24 hours, passing along the African shore, and being felt at Tripoli and the island of Galitta.† An eastern current flows between Egypt and Candia, and at Alexandria. Arrived at the coast of Syria it turns northwards, and then advances between Cyprus and the coast of Karamania. Such currents would necessarily aid in transporting matter both in solution and mechanical suspension, the last-mentioned current especially acting on that brought down by the Nile.

From the lower specific gravity of the water in the Black Sea,‡ the fine detritus, borne into it by the waters of the Don, Dnieper, Dniester, and Danube, would be carried less distances, comparatively, over its saline waters than those of the Nile, Po, and Rhone over the Mediterranean, while from the same cause, supposing an equal force of wind to act upon both seas, any continued suspension of that matter which might be due to the agitation of waves, would be greater in the Black Sea than in the Mediterranean, the waters of the former offering less resistance to the wind from their inferior specific gravity. In the Baltic also, from its specific gravity, the deposit of detritus borne down the rivers discharging themselves into it, would approximate towards that observable in fresh-water lakes. Like most lakes, also, the Black and Baltic seas have out-

---

of rivers into it, or the fall of rain upon it, so that the Black Sea furnishes waters on the one side and the Atlantic on the other, in order to keep it at the height required.

* "On the European side, west of the island of Tarifa, it is high water at 11h, but the stream without continues to run 2h. On the opposite shore of Africa, it is high water at 10h, and the stream without continues to run until 1h; after which periods it changes on either side, and runs eastward with the general current. Near the shore are many changes, counter currents, and whirlpools, caused by and varying with the winds. Near Malaga the stream runs along shore about eight hours each way. The flood sets to the westward."—*Purdy, Atlantic Memoir*. The tide rises three feet at Malaga.

† An under and counter current has been considered to set westward, but of late this has been doubted. However this may be, Admiral Beaufort has shown, while noting the current which flows westward from Syria to the Archipelago, that "counter currents, or those which return beneath the surface of the water, are also very remarkable. In some parts of the Archipelago they are sometimes so strong as to prevent the steering of the ship; and in one instance, on sinking the lead, when the sea was calm and clear, with shreds of bunting of various colours attached at every yard of the line, they pointed in different directions all round the compass."—*Beaufort's Karamania*.

‡ According to the researches of Dr. Marcet (Phil. Trans. 1819), the specific gravities of the under-mentioned seas are as follows:—

Mediterranean . . .	1·02930	Baltic	1·01523
Black Sea	1·01418	Yellow Sea	1·02291

flowing currents,* so that the evaporation on their surface is not equal to the fresh water discharged into them.†

Supposing no counter and constant currents bringing in salt water from the Mediterranean to the Black Sea, and from the German Ocean to the Baltic, and that the discharged waters from both seas carry off the average saline waters of each, these seas would gradually become less saline in proportion to the different amount of salts in solution carried out to the adjoining seas, and those brought in by the rivers discharged into them.‡ Upon this view, therefore, both the Baltic and Black Seas may at previous periods have been more saline than at present. Considering, as geological evidence would lead us to infer, that the area now covered by the Caspian and that occupied by the Black Sea, were once beneath a common sea, changes subsequently effected have separated them as now found. In the Caspian we should have evaporation sufficient to overpower the influence of the fresh water poured in by the Volga, Ural, and the minor rivers, while in the Black Sea the supply of fresh water is beyond the evaporation. Hence the Caspian remains a salt lake, while the Black Sea may be gradually becoming more and more a fresh-water lake, the Caspian not only retaining its original saline contents, but becoming more saline if either the salts brought down by the rivers are beyond any deposit which may dispose of them, or the evaporation be greater than the supply of water from the Volga, Ural or Iaik, and minor streams.§ Upon such an hypothesis, though at first the deposits in each would be under the same conditions, these would gradually change as regards effects arising from the increasing difference in the specific gravities of the respective waters.‖

* The velocity of the current, in the narrowest part of the Sound (Baltic), is about three miles per hour; but the ordinary general rate, in fine weather, is about a mile and a half or two miles. The current flowing from the Black Sea runs commonly, in the Thracian Bosphorus, from three to five miles per hour, according to the direction and force of the winds.

† Strong opposing winds force back the current out of the Baltic, and, if sufficiently long continued, will raise the level of that sea.

‡ In equal weights (3 lbs.) of water taken from the East Friezland coast, and from Rostock in the Baltic, the following proportional differences in saline contents were found:

	German Ocean.	Baltic.
Chloride of sodium	522	263
Muriate of magnesia	198·5	111
Sulphate of lime	23	12
Sulphate of soda	1·3	1
Residue	1·5	1

§ There is considered to be good evidence of the Caspian having stood at higher levels than at present, those more corresponding with the actual level of the Black Sea, beneath which the surface of the Caspian is now 81·4 feet.

‖ A peculiar bitter taste observable in the Caspian waters is attributed to the

Although ice may form in the shallow bays of the Black Sea, and the branch known as the Sea of Azof be often frozen over in the winter months, so that ice, floating away from the coasts, may be the means of conveying fragments of rock and pebbles into situations to which they would not be otherwise transported, the ice in the Baltic, from the geographical position of that sea, is a means of adding to deposits in it of a more important kind. In particularly severe seasons, extensive sheets of ice over parts of this sea occur, and cases are recorded where great distances could be, and were traversed by travellers. Large areas are commonly frozen for nearly three months in the year, the ice on the south commonly breaking up in April, while in the Gulfs of Bothnia and Finland it may continue until the middle of May. Though the Baltic may be, as regards the ordinary acceptation of the term, tideless, it is nevertheless liable to those local changes of level which are due to the pressure of powerful winds blowing for a time from particular points, and it is described as often vexed by such winds. Ice, therefore, around the shores of its numerous islets and uneven coasts, may often be broken up, particularly towards the warmer weather, with shingles from the shore, and fallen fragments from the cliffs in and upon it, and be transported seaward, the shingles and pieces of rock being there deposited, and thus adding gravels and distributed angular fragments to and among the more common accumulations formed in this sea, the depth of which varies from shallows, backed by marshes, to two localities on the south-east where the line gives respectively 110 and 115 fathoms of water.*

The Gulf of Mexico, its waters forced up by the pressure acting from the Atlantic through the Caribbean Sea, may, for geological purposes, be considered as a tideless sea, with, among others, a great river, the Mississippi, delivering matter in solution and mechanically suspended into it. The great movement of water coming round the Cape of Good Hope from the Indian Ocean, and considered as a constant current produced by the trade winds, assisted by the motion of the earth, sets from the Ethiopic Sea, united with an equatorial current of the Atlantic, across that ocean, against the West Indian islands. This pressure forces a constant stream of water into the Mexican Gulf, by the western side of the

presence of naphtha, which abounds in some localities on its shores. The basin of the Caspian appears of very unequal depth, this varying from the steep coast extending from the Balkan Bay to that of Mertroï Kultyuk - off which a line of 450 fathoms does not reach the bottom in some places— to long-continued, very shallow shores in others.

* The general depth has been estimated at 60 fathoms.

Yucatan Channel, with commonly a reflow close to Cape Antonio, at the west extremity of Cuba. Thus pressed up, the waters escape between Cuba and the Florida reefs in the current known as the Gulf Stream;* so that the waters in the Gulf of Mexico form a kind of comparatively tideless sea, in which deposits are effected much as in the Mediterranean. Though other rivers throw detritus into this area, collectively of much importance, the Mississippi is that, by its additions to the land, and by the discharge of matter mechanically suspended in its waters, which is the most important. The following is a plan (fig. 59) of the very characteristic advance of deposits from this river into the waters of the gulf.

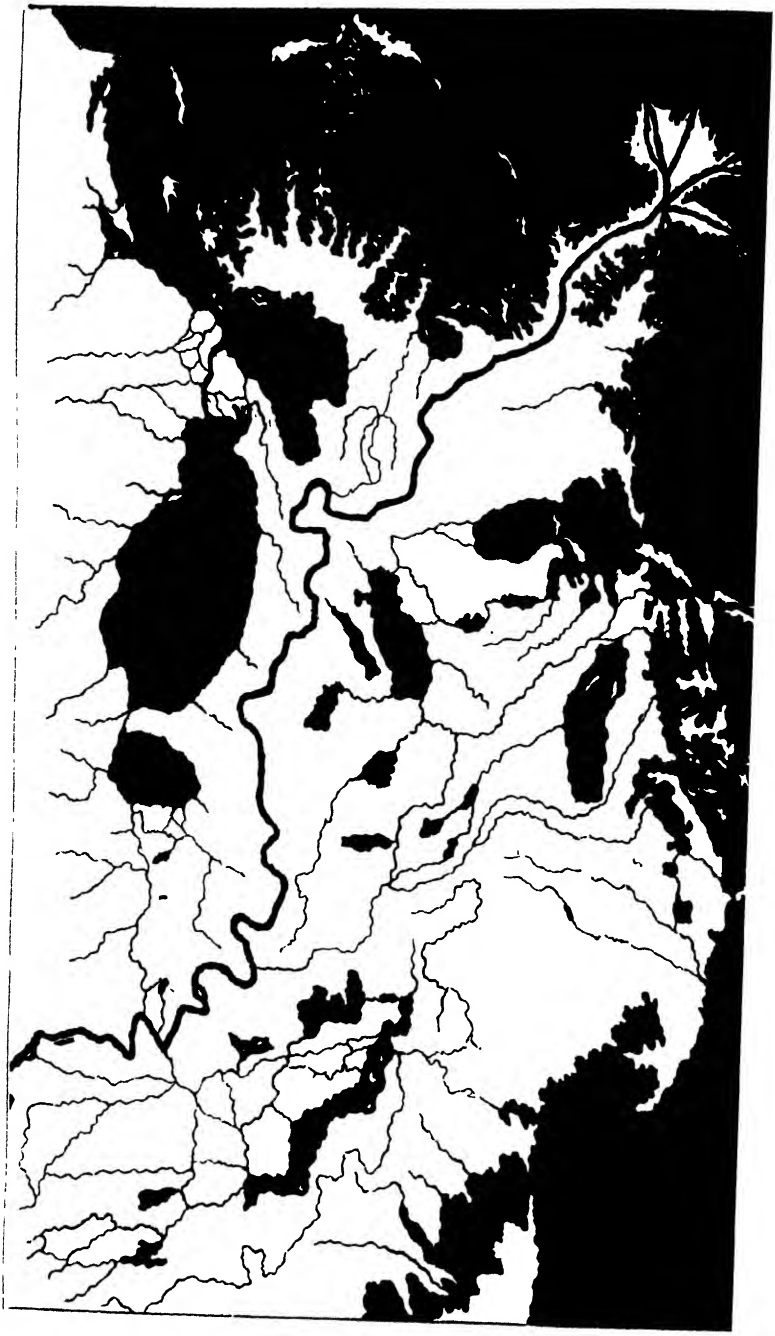
The manner in which the main channel is bounded by lines of bank, rising above the sea, towards its final outlet, well marks the retardation produced by the friction of the banks as they arise. The various lakes, with the cross channels, are also highly illustrative of this order of accumulation.

As might be anticipated, when the fall of the Mississippi, during its greatest floods, is estimated at only one inch and a half in a mile between New Orleans and the sea, a distance of about 100 miles—while, when its waters are low, the fall is scarcely perceptible for the same distance—little mineral matter can be carried seaward in mechanical suspension, beyond that which, when deposited, would form silt, mud, or clay. This great river, therefore, now throws little other than fine mineral matter into the Gulf of Mexico, that which rises by accumulation above the surface of the sea being liable to be sifted by the shore waves, as at the mouths of the Nile. A vast mass of this fine sediment must have been thrown down, and is now accumulating in the Mexican Sea; the chief addition to such mass of mud or clay, independently of the hard remains of fish, crustaceans, and molluscs, being wood, the transport of which down the Mississippi and its tributaries is most abundant. Not only is this wood arrested in its progress in various places, or entangled among the channels of the delta, but much of it passes out seaward. Millions of logs and trunks of trees are transported several miles outwards during floods, so that it becomes difficult to navigate among them.†

* The breadth, length, and velocity of this long-celebrated current would appear, to vary. Winds often affect it, diminishing its breadth and augmenting its velocity, or augmenting its breadth and diminishing its velocity.

† Captain Basil Hall, *Travels in North America*, vol. iii.

Fig. 59.



CHAPTER VI.

DISTRIBUTION AND DEPOSIT OF SEDIMENT IN TIDAL SEAS.—BARS AT RIVER MOUTHS.—RISE AND INFLUENCE OF THE TIDES.—DEPOSITS IN ESTUARIES.—DELTA OF THE GANGES—OF THE QUORRA.—DEPOSITS ON THE COAST NEAR SWANSEA.—INFLUENCE OF WAVES.—FORM OF THE SEA-BED ROUND THE BRITISH ISLANDS.—INFLUENCE OF CURRENTS.—SPECIFIC GRAVITY OF SEA WATER.—DISTRIBUTION OF SEDIMENT OVER THE FLOOR OF THE OCEAN.

UPON the coasts of the continents and of islands amid the ocean waters, not only is there a rise and fall of the sea-level twice in each day, but the river waters discharged into the ocean are, for the most part, ponded back by each rise of the tide, to be let loose at its fall with so much of the sea water as had been forced up the river channels during the flood tide. Here we have a very material modification of the discharge of the matter, either in solution or mechanically suspended in the rivers, as compared with its delivery into tideless seas by them. According to the varied character of the rivers where they discharge themselves into tidal seas; as regards the greater or less amount of water in them at different times; the kind of coast at their embouchures; depth of water, exposure to prevalent winds, and other conditions; so, no doubt, is the delivery of these waters modified; but in all they are exposed to checks from the rise of tide at their mouths. The opposition of the sea to the rivers at the height of the tide necessarily varies with the change from neap to spring tides; the amount of check which the sea gives to the outflow of the fresh water, thus alternating, on the minor scale; though, as a whole, a very constant effect is produced, the greatest resistance being offered at the heights of equinoxial spring-tides.

From the check thus given to the discharge of waters containing matter in mechanical suspension, or pushed forward by rivers in their channels, there is a tendency to form accumulations across the course of rivers, commonly known as *bars*. These will be found to occur variably, according as the real mouth of the river may be high up a deep branch of the sea (or in other words, where the sea

level may cut high up a valley or depression, which thus becomes partly subaërial, partly submarine), or be situated on the general unbroken line of a coast, even, perhaps, protruding beyond it, into shallow water. It will soon be perceived that the breakers become important aids in the accumulation of bars according to such conditions; having little influence high up an arm of the sea, particularly where the channel is narrow, but assisting most materially in their formation when acting upon an exposed coast, more especially if the mouths of the rivers be open to strong and prevalent winds. This combination of checks given to waters pushing forward and carrying detrital matter in mechanical suspension, and by breakers striving again to thrust back that matter, produces bars at the mouths of many rivers, alike important as regards the subject under consideration, and the intercourse of nations.

The effects of tidal action in, for the time, arresting the outflow of rivers, will much depend upon the heights which the tides, on the average, attain; and it will readily be seen that, acording to the obstacles opposed to the tidal wave, and the form of the shores against which it moves, will be the change of sea level between high and low water. In the open ocean, where the tidal wave meets with, comparatively, little opposition, we find the difference of the sea level at high and low water far less than among funnel-shaped channels, and other favourable combinations of coast. Thus, while among the eastern Polynesian islands in the Pacific Ocean the tides rise and fall about 2 or 3 feet,* and in the Atlantic from 3 feet at St. Helena, and 4 to 6 feet at the Cape de Verde Islands, to 8 or 9 feet at Madeira, the equinoxial spring-tides in the Bay of Fundy rise from 60 to 70 feet.†

An observer need not travel from the shores of the British Islands to study the dependence of the rise and fall of tide upon local conditions: many situations will afford him the requisite opportunities. The Bristol Channel, since it fairly faces the tidal

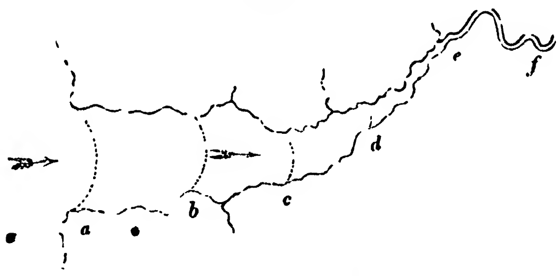
* According to Mr. Dana (Geology of the United States' Exploring Expedition, 1838-42, p. 26), the tides rise only 2 or 3 feet through the eastern part of Polynesia; at Samoa 4 feet; at the Feejee Islands 6 feet; and at New Zealand 8 feet.

† A glance at the map will show how favourably this bay is situated for receiving a body of flood tide driven up between Cape Cod (Massachusetts), and Cape Sable (Nova Scotia), and forced onwards into Chignecto and Mines Bay. Though there is a very considerable bay between Gaspé Bay (Canada) and the North Point (Breton Island), on the north of the narrow isthmus separating Nova Scotia from New Brunswick, neither its form, nor the set of tide into it, cause a rise of water beyond about eight feet. There is, therefore, from local causes, a difference of high water, on either side of this narrow isthmus.

wave coming from the Atlantic, may be taken as a good example of a considerable rise of tide produced by the narrowing of an arm of the sea. Though strictly not an unmodified ocean tide, since the wave has to pass over nearly 300 miles of soundings, within the edge of the 100 fathoms line, before it strikes the Land's End, the change from the rise of 18 or 20 feet at St. Ives, Cornwall, to that of 46 to 50 feet at King Road (Bristol) and Chepstow, is striking; more particularly as the tides of 30 feet at Lundy Island, and 36 feet at Minehead, show this rise to be gradual. From the increasing elevation of channel, and friction, beyond Chepstow and King Road, and the withdrawing of the tidal pressure from behind when the ebb begins seaward, the height of tide soon decreases up the Severn. The tidal waters, however, so suddenly check the discharge of the river waters, that the latter are as suddenly forced back, the flood-tide rushing forwards in a great wave commonly termed the *bore*, and causing an instant rise of several feet in the lower part of the river, gradually fining off to the termination of all tidal action in the Severn.*

The annexed plan (fig. 60) will illustrate the example here

Fig. 60.



given. At *a* the tidal wave begins to be higher than in the open sea. At *b* its elevation is increased from the decrease of the depth and breadth of the channel; and at *c*, from similar causes, the height of tide is still greater. We may assume, for illustration, that at *d* the tidal wave becomes most elevated, and that afterwards, towards *e*, from the absence of propelling power behind, from the actual fall

* The same sudden rush of the flood, overpowering the ebb in tidal rivers, is observed in many other localities. The *bore-wave* up the Ganges is described as so rapid, that it scarcely takes four hours passing up a distance of nearly seventy miles, sometimes causing an instantaneous rise of five feet of tide at Calcutta. The boats on the shore on which it breaks take to the middle of the river for safety on its approach. A considerable bore-wave is stated to be observed at the mouth of the Maranon, or Amazons, during the equinoxes. The chief wave is from twelve to fifteen feet high, followed by three or four others. Its advance is very rapid, and its course is stated to be heard at the distance of two leagues.

of water on the ebb towards *c*, *b*, and *a*, and from the general rise of the channel, the tidal wave becomes less and less felt, until at *f*, its effect entirely ceases. The *bore* will depend upon local causes; but under the conditions noticed, the sudden check to the outflowing river, and corresponding sudden rise from the inflowing flood-tide, are not unfrequent, though the bore may not always be sufficiently important to arrest attention.

The English Channel affords us another good example of a considerable rise of tide produced by local obstacles, and the more instructive, as this rise does not extend across to the oppose coast, as is the case in the Bristol Channel. On the French side, the land of the Cotentin, terminating with Cape La Hogue, and the islands of Alderney, Guernsey, and Jersey, with the multitude of isles, islets, and rock, in the Bay of St. Malo, oppose a direct obstacle to the progress of the tidal wave coming from the Atlantic, while the English coast presents no such obstacle. In consequence, the sea level at high water is raised higher on the one side than on the other; and while the tides only rise 13 feet at Lyme Regis, 7 feet in Portland Road, 15 feet at Cowes, and 18 feet at Beachy Head, the difference of high and low water is 45 feet between Jersey and St. Malo, and 35 feet at Guernsey.

Not only are there these differences in the rise of tide from local causes, but the relative direction of the flood and ebb, with their consequent currents, also vary materially in some situations. Thus, at the Land's End the flood-tide runs 9 hours to the north, and the ebb 3 hours to the south; and numerous other modifications of the same kind, where the times of flood and ebb are different, are to be found on the coasts of the British Islands.

As regards the distribution of detritus by tidal streams, the direction of the latter will not only be found to change considerably during the progress of theflood or ebb, as the case may be, off many parts of coasts, but the ebb very frequently commences on shore, while a flood-tide is continued in the offing.*

As so much, not due to the friction of tidal streams on coasts has been attributed to it, instead of to the action of breakers—a destructive action more particularly felt when strong on-shore winds and high tides are combined—it would be well for an observer to study the velocity and transporting power of tidal waters on the

* It has been held that "the length of time between the changes of tide on shore and the stream in the offing is in proportion to the strength of the current and the distance from land; that is, the stronger the current, and the greater distance that current is from the land, the longer it will run after the change on the shore."—*Purdy, Atlantic Memoir.* 1829.

sea-shore. Those who dwell on, or visit, the coasts of the British Islands, where, fortunately, so many modifications in tidal streams may be more or less easily studied, will soon learn properly to estimate the value of tidal friction on land.

With respect to the tides around the British Islands, those flowing amid the Orkney and Shetland Islands, and through the Pentland Frith, between the mainland of Scotland and the former, would appear to be among the strongest. They vary considerably in force, according as they are neap or spring tides. While in Stronsa Frith and North Ronaldsha Frith the former only run at the rate of 1½ mile in the hour, the latter make a stream of 5 miles an hour. In the Pentland Frith, the spring-tides are stated to have a velocity of 9 nautical miles an hour, while at neap-tides they do not exceed 3 miles.*

Round the more prominent headlands, the tides, as we might expect, run with greater velocity than in the bays on each side of which they project, or in the offing outside. The tidal wave striking the headlands, and rising locally from this opposition, escapes round to the next bay, thus causing an accelerated stream of tide for a short distance. The friction of the water on the land is, however, commonly sufficient very materially to diminish the strength of the stream in immediate contact with it; so that, in calm weather, when the force of the tide is neither impeded nor accelerated by the force of opposing or favouring winds, chaff or other light bodies thrown into the sea will be seen to pass in a comparatively slow course along shore, while a strong stream of tide is running outside.

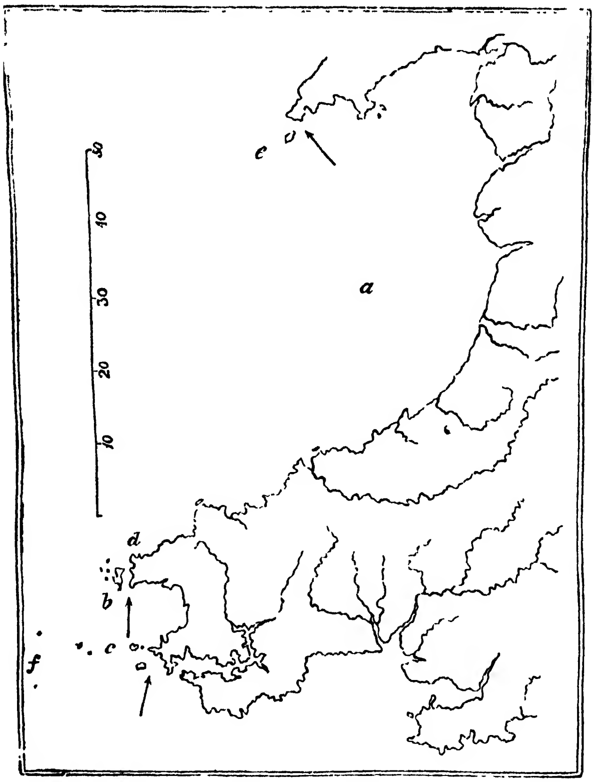
How little friction takes place in such situations may often be well seen by the presence of a coating of barnacles, or of sea-weeds, even upon steep headlands, though exposed to the action of breakers, these being, off such deep-water headlands, commonly unaided in their action by sand or gravel in mechanical suspension. It is desirable that the observer should carefully watch the shores of any district he may be examining, with respect to tidal friction, during calm weather, and from neap to spring tides. Except in the most exposed situations, he may perceive how rarely even grains of sand, much less small loose shingle, can be moved by any stream of tide in contact with the coast.

* The flood-tide there comes from the north-west, and is not of unusual strength until it meets with the obstacles of these islands and the mainland. The change of tide sooner on shore than at a distance from it, varies according to situation, amounting in some places to two or three hours.

The retarding effect of friction on the headlands is often well exhibited near the strong streams of tide off them, known as *races*, so dangerous, frequently, when opposed to powerful winds. Though the tides run in such situations with the greatest force of the locality, and the waters are thrown about in various directions, it often happens that, between the race and the headland, there is more quiet water, sufficiently broad for the passage of a boat in moderate weather.

Tidal waters rush with great force through channels formed between the horns of great bays and islands at a short distance from them; such is the case with the horns of Cardigan Bay and of St. Bride's Bay on the south of it, as shown in the following plan (*fig.* 61), where *a* represents Cardigan Bay, and *b* St. Bride's Bay.

Fig. 61.



Foul rocky ground extends from the Smalls Light, *f*, to Skomer Island, *c*; between which and the mainland there is an exceedingly strong tide sweeping close to the cliffs. Supposing this to be a flood-tide, its force is diminished and almost lost in St. Bride's Bay, *b*.

This bay receives the flood-tide, not only through this channel, but also directly from the Atlantic; its flow over the foul ground between the Smalls Light and Grasholm, and thence to Skomer, being marked by broken water. Part of the tide driven into St. Bride's Bay escapes with much force between the mainland and Ramsay Island, and round the latter and the rocks and islets known as the Bishop and his Clerks, *d*, into Cardigan Bay. The latter also receives an abundant supply of the tidal wave direct from the Atlantic; and the flood passes with great strength between its northern horn and Bardsey Island, *e*.

In the chief channels noticed, no doubt little comparatively fine sedimentary matter could rest in the run of such tides, and any that might be thrown down by the eddies of one tide would probably be removed by the reverse action of the other; but these effects would be very local. That hard rocks readily resist such friction is well shown in the localities mentioned, barnacles and sea-weeds being commonly discovered on the sides of the channels at low water.

It will be at once perceived that the flood-tide passing up rivers would act very differently, according as the channels were continued deep outwards, or crossed by bars accumulated at their mouths. In the former case, the sea waters being specifically heavier than the river waters, as it were, wedge up the latter, discharging outwards, until the levels are so changed that the whole body of tidal water is driven inland, forcing and ponding back the fresh water.* In the more favourable situations of this kind, therefore, where great floods are running down a river, the heavier waters of the first of the flood-tide may be passing up the river while the lighter waters above are running outwards. In bar rivers the sea waters pour over the bars, and, if the channels be afterwards shallow, drive the river waters at once before them, while, if behind the bar there be water of much greater depth, as sometimes happens, the heavier sea waters first flow into the basin and raise the waters in it, so that when sufficiently elevated with the increasing tide, the whole passes up the river with the flood-tide, forcing back the fresh water. Between the action of the tide in such rivers as the St. Lawrence,† with its open estuary or arm of the sea, and the Ganges

* The passage of river waters outwards during freshets, from heavy rains in the interior, while the flood-tide waters are flowing beneath in a contrary direction, may occasionally be seen well shown when large vessels are at anchor in an estuary, as, for instance, in the Hamoaze, Plymouth, riding with their heads to the flood-tide, being sufficiently deep in the water to be influenced by it, while small boats, secured alongside, ride with their heads in the contrary direction, the outflow of the higher and fresh water alone acting upon them.

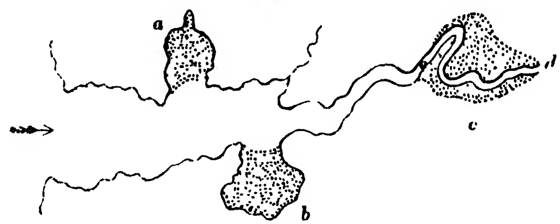
† The St. Lawrence affords a good example of the greater velocity of an ebb over a

and Quorra, the deltas of which protrude into the ocean, the one in the Bengal Sea and the other in the Gulf of Guinea, every modification will be found in the tidal rivers of the world.

While checked by the flood-tide, the waters of estuaries will deposit such of the matter, which they may hold in mechanical suspension as the time will permit, and according as the estuary waters may or may not be agitated by the friction of the winds. Slight observation is sufficient to show that highly-discoloured water is commonly found in estuaries, and that this is borne upwards and downwards by the tides, escaping seawards during the ebb in some estuaries in one direction, while the rivers add detrital matter to these bodies of water in others. In estuaries like the Severn, at the head of the Bristol Channel, the muddy water is carried backwards and forwards with such rapidity that it is only in the sheltered nooks and situations that it can find rest sufficient to deposit fine sediment, including among them the shores where retardation by friction also produces a sufficient state of repose during the tides.*

Many minor estuaries round the coasts of the British Islands show the filling up, not only of the sheltered places on their sides, but also of their upper parts, where detrital matter is gradually accumulated. If the course of the river has not been long through a level country, the deposits at the heads of estuaries may even be gravelly, while mud only is accumulated in the sheltered localities. If the annexed plan (fig. 62) represent one of these estuaries, then it will

Fig. 62.



usually be observed that the accumulation at the head *c* is more gravelly or sandy, particularly in its lowest parts, than in the sheltered situations, *a* and *b*. At *c* we have not only the heavier matter

flood-tide in an estuary. Where the ebb from the Saguenay unites with that of the St. Lawrence, it passes outwards with considerable strength, and is stated to run seven nautical miles per hour between Apple and Basque Isles. While the ebb is thus strong, the stream of flood-tide is scarcely perceptible.

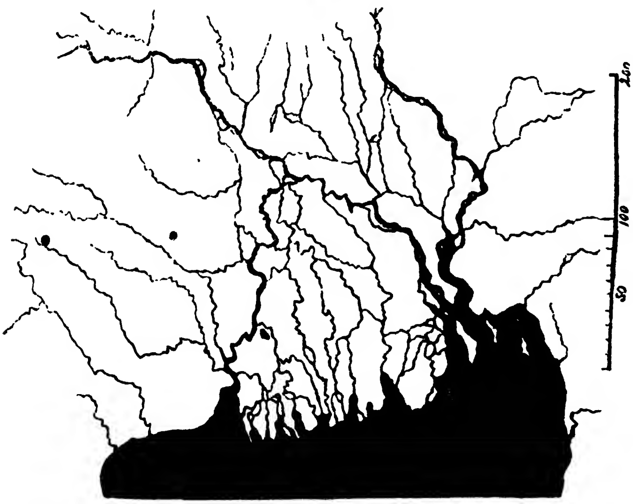
* The difference of the friction on the sides of these estuaries, where mud is deposited, and more outwards in the stream of tide, is commonly well shown by the sandy bottom under the latter, the friction of the water being too great to permit finer sediment to remain in such situations.

thrown down by the check of the tide there felt, but also all the detritus which can be pushed along the bottom by the river *d*, during the ebb of the tidal waters, and during the common discharge of the river water when the tide has fallen, a combined time in some localities equal to nine and ten hours in each twelve. At *a* and *b* the fine sediment is commonly accumulated to the level of the highest ordinary spring-tides.

In estuaries of this class we should anticipate that there would be much gain of land where the discharging rivers entered them, and, accordingly, in such situations we often find extensive marshes and flats, which would justify this expectation, even if historical evidence could not be adduced. Of such evidence, however, there is commonly no want, and the heads of many estuaries around the British Islands, and along the ocean coasts of Europe, are known to have become more shallow and even to have moved further outwards, dry land supplying the place of marshes, and mud banks, within historical times.*

The mouths of the Ganges, extending across a distance of about two hundred miles (fig. 63), furnish us with the discharge of de-

Fig 63.



trital matter into a tidal sea of a different character. Here the abundance of the outflowing waters, particularly during floods, is sufficient to carry out a delta, more resembling those observed in tideless seas. In times long since passed, the Ganges may have discharged itself into an estuary, as far northerly as the com-

* These changes produced, independently of sea banks raised to keep out the tides.

mencement of its delta, now more than two hundred miles from the sea, and into the same estuary, the Brahmaputra may have delivered its waters, these two great drains of land extending to the Himalaya mountains having gradually filled up such an estuary, by depositing the matter transported mechanically in, or swept onwards by them. Coarse gravel is not forced forward by the Ganges within four hundred miles of its mouth, so that the sedimentary matter discharged into the sea is of a finer character. To this discharge, both by friction on the bottom and in mechanical suspension, checks are offered by the tides; but the body of fresh water is so considerable, as compared with such checks, that the sedimentary deposits rapidly gain upon the sea, notwithstanding that the general depth beyond the mouths of the Ganges is by no means inconsiderable. Innumerable changes in the direction of the various streams into which the delta is divided are produced inland.* The course of this river is described as affording good examples, on the great scale, of the alterations of channel, from the accumulation of banks upon small obstacles, to be equally well studied, as regards general principles, in hundreds of little streams. Thus a tree arrested in its course will produce an accumulation, gradually rising into an island, to be again swept away by another change of channel.

The great body of fresh water discharged by the Ganges in floods seems, to a great extent, to overpower the influence of the tidal wave, so that detrital matter then becomes accumulated more in the manner of the Nile, Rhone, Volga, and other great rivers, discharging themselves into tideless seas.† At the junction of the Ganges and Brahmaputra, below Luckipoor, there is a large gulf in which the water is scarcely brackish, and during the rainy season the sea is stated to be overflowed by fresh water for many leagues outwards.

In the Quorra we have an example of a similar kind, and a vast

---

* Major Rennel states that during the eleven years he remained in India, the head of the Jellinghy river was gradually removed three-quarters of a mile further down. He observed also, that "there are not wanting instances of a total change of course in some of the Bengal rivers. The Cosa (equal to the Rhine) once ran by Purneah and joined the Ganges opposite Rajenal. Its junction is now nearly forty-five miles further up. Gour, the ancient capital of Bengal, once stood on the Ganges."—*Phil. Trans.* 1781.

† The amount of detrital matter borne outwards by the Ganges has been estimated at about 2½ per cent., and the average discharge of water at 500,000 cubic feet per second.—(*Gleanings of Science*, vol. iii. Calcutta, 1831.) If we take the quantity at 2 per cent., and consider the transported matter to give 15 cubic feet to the ton, we should obtain 57,600,000 tons per day, equal to a mass of ordinary granite, having a base of 1,000,000 square feet, rising to the height of 864 feet.

body of fresh water thrusts out a delta into the ocean. The great stream of water is checked, not overcome, in mid-channel, though felt between 30 and 40 miles up the river. In this river, and in many other tropical rivers, mangrove-trees add materially to the power of forming new land.* Wherever sufficient shelter can be obtained, they establish themselves in abundance; their stilt-like roots entangling any floating substances washed near them; producing a repose fit for the deposit of the finest sediment, and affording shelter to an abundance of reptiles, fish, crustaceans, and molluscs, which seek and enjoy the protection they afford.

When we regard the sea-shores of the world exposed to tides, we see a great destructive power in the breakers, as a whole in ceaseless action, grinding back and levelling off the land, and throwing a mass of matter into the tides sweeping round such shores, which mass, added to that thrust out of the rivers, has to be distributed by the streams of tide and such ocean currents as can receive any portion of it. Great rivers, as we have seen, may transport matter in mechanical suspension far outwards, particularly when swollen by floods, and thus place it within the distributing influence of the ocean currents. Through these it may take a long time to descend into those quiet depths where it can find a rest, one that may continue undisturbed until, perhaps, after a long lapse of geological time, the resulting deposit may be upraised, and placed within the destructive influences of the atmosphere and surface waters.

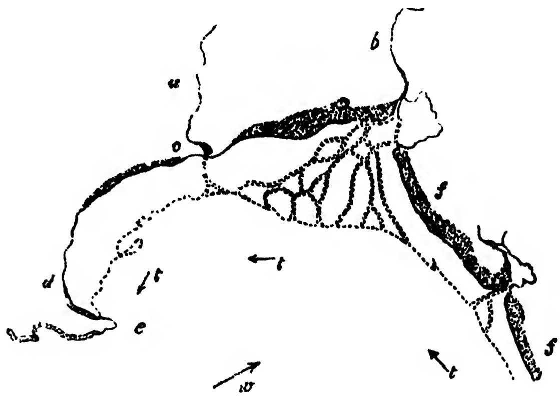
When detrital matter is thrown into the tides, it is borne to and fro by them, according to their flow and ebb, and the observer will have abundant opportunities of seeing on the coasts of the British Islands, and on the ocean shores of Europe, that the river waters when swollen by rains, bear outwards with the ebb, and in the direction that it takes along shore, much mechanically-suspended detritus, which does not again enter the rivers unless under very favourable circumstances. As a whole, much fine detritus, thus derived, is carried coastwise by the ebb, and accumulations are formed of it, if there be sufficient continued repose in that direction. So that should a sheltering headland run out, and a bay be formed between it and the embouchure of the river, there is a

* Alluvial land is described as forming into flat islands, covered by mangrove-trees and papyrus. These are sometimes so acted upon by floods as to be partially or wholly swept into the ocean. Professor Smith noticed a floating mass, probably washed out of the Congo, about 120 feet long, consisting of reeds resembling the *Donax* and a species of *Agrostis*, among which branches of *Justicia* were still growing, further north off the coast of Africa.--*Tuckey's Expedition to the Zaire or Congo.*

tendency to deposit the finer sediment in the locality so sheltered. We may take the coast of Swansea as affording an easily-observed instance of the separation so affected.

Two rivers, *a* and *b* (fig 64), the Towey and the Nedd (Neath),

Fig. 64.



when in flood, bring down much sedimentary matter, the finer parts of which are carried by the ebb tide (*t*, *t*, *t*) towards the bay formed between Swansea (*c*) and the Mumbles (*d*). Here finding the necessary repose, the prevalent winds (*w*) blowing from the west and south-west, a part is deposited and mud is accumulated, the remainder of the detrital-bearing waters, escaping round the Mumble Rocks (*e*) into the general ebb tide passing westwards down the Bristol Channel. While this happens with the finer sediment, the arenaceous part of the detritus thrust out of the river is more quickly thrown down, and a large part of it becomes acted upon by the breakers, raised by the prevalent winds, and is forced partly into mechanical suspension during heavy gales, and then borne in the flood-tides, and partly brushed onwards by the waves, breaking upon much flat ground exposed at low water, towards the coast to the eastward (*f*, *f*). Here the conditions for the accumulation of sand-hills obtain, and the overplus of arenaceous sediment, borne outwards by the Towey and Nedd, and not retained by the sea, is blown by the winds upon the dry land. In this locality, therefore, the river-borne detritus, thrown into the tides, becomes in a great measure separated, mud being chiefly accumulated in one direction, sand in another, a surplus of the latter being restored to the land.

Though there is a tendency to accumulate the finer river-borne detritus in the direction of the ebb tides, this is often met by conditions so unfavourable to such a deposit that the finer matter does

not there come to rest, but is gradually transported outwards to sea, and may thus be brought by tidal streams even within the influence of ocean currents. On a shallow coast the breakers alone, when they can act equally in the direction of the ebb and of the flood-tide, prevent the accumulation of the finer sediment, which, in consequence, can only find rest by being carried outwards into water of the needful depth and tranquillity.

The abrasion of coasts by breakers being the same, whether the tide be setting in one direction or another, as flood or ebb, the finer matter is carried in mechanical suspension equally by the stream of either along the coasts, finding rest in the situations where conditions are favourable, even entering estuaries by the flood-tide, when such estuaries occur in the line of its course, the indraught, on the flood, carrying it in with the tide. As we have seen (p. 54), the heavier parts, such as shingles and small pebbles, are distributed along shore, and the arenaceous portions, sometimes on the coast, sometimes more seaward, according to circumstances.

The agitation of the sea is felt at different depths in proportion to the magnitude of the waves raised by the friction of the wind. During heavy gales of wind, the depth at which this agitation has been observed, sufficient, as it were, to shake up fine sediment enough to discolour the water, is about 90 feet.* The disturbing effects of waves in minor depths is often well shown on shallow sandy coasts by the throwing on shore of many molluscs in a living state, known to inhabit the sands at moderate depths. By the agitation of the sea their sandy covering is removed, and they are swept onwards beyond their powers to retain their position at the bottom, and thus become finally thrown out upon the coast.

Besides the waves seen to arise on the spot from the action of the winds, the great indulations which are known as *swells* and *rollers* (so common on ocean shores, and due to the friction of winds out at sea which do not reach the land) disturb the sea bottom to a considerable extent, so that, both heavy seas and swells combined, the finer sediment becomes removed from all but favourable situations outwards, and is distributed off the coasts, outside the accumulations fringing them, and due to the action of the breakers.

The flow and ebb of the tides produce a motion tending to smooth out and flatten the accumulation of detrital matter deposited on the sea bottom within their influence. The smoothing action no doubt

* The depth at which the disturbing action of a sea-wave can be felt has been estimated even so high as 500 feet on the Banks of Newfoundland. *Emy*, *Mouvement des Ondes*, 1831, p. 11.

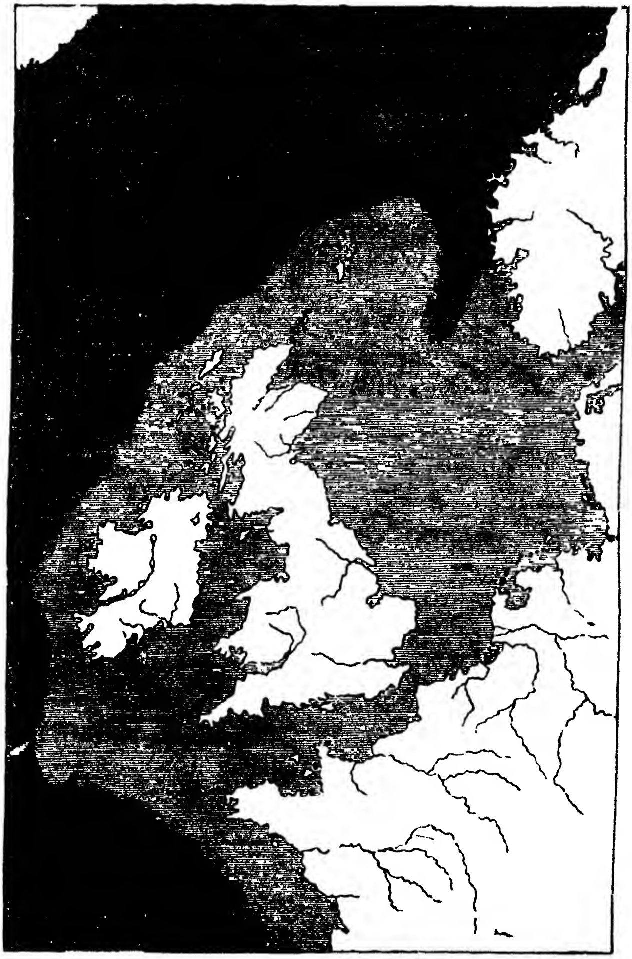
varies with the strength of the tides, as these may be springs or neaps, so that matter can be brought to rest during the latter, which becomes removed by the superior velocity and volume of water of the former; but, as a whole, there arises an adjustment, producing a sea bottom of a marked character. The friction of the tidal wave on the bottom forms ridges and furrows of the same kind with those previously noticed as produced by the winds on loose sand (p. 59). Where clear waters prevail, and the ridges and furrows are formed by this kind of friction alone, the resemblance is very striking, allowance being made for the relative weight of the particles of sand in the air and in the water. Where waves act on the bottom, it would be expected that such ridges and furrows would be modified by the to-and-fro action set up, although the on-shore might be greater than that of the counter movement, in proportion as the wave takes the onward force of a breaker, the higher part acquiring gradually a greater forward motion as the water becomes shallower, and the friction on the bottom becomes increased.

Almost every extensive sandy flat left by the tide, and of such the coasts of the British Islands afford abundant examples, shows the effects of friction on the sand. An observer should well study the various modifications to be seen in such situations, for among arenaceous accumulations of all geological ages, the effects of friction on sand and silt, by water in motion, is often very evident. In many situations peculiar arrangements of the surface sand will be observed to have arisen from the draining off of the tidal water, which has quitted a large tract of sand suddenly. We have thus friction on the bottom from the rise and fall of tidal waters on coasts, from the to-and-fro action of waves produced by winds (where the depths are favourable), and from streams of tide, variable in strength, usually acting in two directions, and often in more, from local causes.

From friction of all kinds much sedimentary matter is so shoved and pushed along the bottom in various directions, that from this cause alone a great flattening of the surface would be effected. If to this we add the deposit of matter borne in mechanical suspension, and derived either from rivers or the action of breakers, we should expect a distribution of detritus which, if raised above the level of the sea, would offer the appearance of a great plain. The accompanying map (fig. 65) will show the extent of area around the British Islands within a line of depth equal to 100 fathoms (600 feet), and which, if raised above the level of the sea,

would present to the eye little else than a vast plain. To form this great tract of smoothed ground, no doubt the levelling action of breakers, cutting back the coasts, must be duly regarded; so that to this action, to that of the seas rolling in various directions, according to the winds stirring up the bottom in sufficiently shallow places, and to the distributing power of streams of tide, is mainly

Fig. 65.



due the present surface of this area,* the extent of which may be estimated by the annexed figure (fig. 66), representing 1000 square miles, on the same scale as the map (fig. 65).

* Always bearing in mind that there is a base beneath of tertiary and other rocks, over which the sands and mud are at present strewed, and which may here and there be still uncovered. In many a situation, a minor area, planed down by the action of

Fig. 66.

It is worthy of remark, that if, instead of the line of 100 fathoms beneath the sea, that of 200 fathoms had been selected, the second line would not have extended far beyond the first, the slope increasing far more rapidly outside the 100 fathom line than within it, so that, after preserving a very gentle slope, as a whole, outwards for the great area represented above (fig. 65), the bottom of the sea descends much more suddenly beyond it towards the Atlantic.*

Slight attention on the coasts will show that the water moving past them in a stream from tidal action travels backwards and forwards a somewhat limited distance, so that any detritus held by it in mechanical suspension, and eventually thrown down from such suspension, could only be deposited within a limited area, when no disturbing causes interfered. The water of a tidal stream, passing a coast at the average rate of three miles per hour, will only travel 18 miles, regarding the subject generally, before it is swept back again over the same ground for the like distance. The pressure of high winds, both on and off a coast, particularly if they be long continued, forces water against or away from the land, and so with any other direction a surplus of the ordinary body of water may take from the friction of the wind. Hence the mere backward and forward motion of the same body of water is somewhat modified, as also by the great additions made to the usual volume of tidal water by the discharge of great floods from rivers, striving to force their way over coast streams of tide.

Making, however, all reasonable allowance for these modifying influences, there remains enough of continued local action to procure local accumulations of detritus, more diversified in character near the coasts than at a distance from them, on account of the increased velocity of tides immediately off chief headlands, and their diminished strength of stream in sheltered bays, not forgetting estuaries, with and without bars of different kinds.

The observer has now to consider the distribution of fine matter in mechanical suspension by means of ocean currents. Some of

---

the breakers, may yet be kept clean from deposits by local causes. We may probably regard the whole area as the result of the cutting back of coasts by breakers, and of deposits from the causes pointed out, continued through a long lapse of geological time, movements of land, as regards its relative level with the sea, and on the large scale, having contributed to its present condition.

* Here and there, there are minor depressions in this area, and among them the trough-like cavities in the North Seas, known as the Silver Pits. The bottom around the chief pits is described as rising gradually to it, when suddenly the interior sides descend from a few to 40 or 50 fathoms, forming steep interior escarpments.

these are known to be very constant in their courses, others periodical, and many temporary. We have seen that the pressure of strong and long-continued winds forces up water by their friction on its surface in tideless seas, and consequently would expect that in the open ocean similar winds would force water before them, though the absence of land would produce a modification in the result. When the area so acted upon was bounded by a single range of coast, the modification would be less; and when two lines of coast presented themselves, between which the water could be forced, and lateral fall prevented, there would be an approximation to the effects observable at the north and south extremities of the Caspian, or on the east and west shores of the Black Seas, where the waters are pressed forward by the needful winds.

Independently of the pressure on the surface of the sea by winds either constant or nearly so, periodical or temporary, it has been supposed that the motion of the earth gives a certain movement to the waters of the ocean from east to west, thus increasing the power of some currents, due to the surface action of winds, and interfering with the movement of others. To the motion of water from this cause, the continent of America, with South Georgia, South Orkney, South Shetland, and the icy regions extending to Victoria Land, would interpose between the Atlantic and the Pacific, and the continent of Asia, with the Philippines, Borneo, Moluccas, New Guinea, and Australia, would oppose the westward movement of the Pacific, not forgetting New Zealand, and the multitude of islands and islets of Polynesia in that ocean.

The more open space for this supposed movement would be from the Indian and Southern Oceans into the Atlantic, the coast of Africa not offering it opposition beyond the latitude of 35° south. A constant current does run out of the Indian into the Atlantic Ocean, flowing up the west coast of Africa, to the equatorial regions, whence it strikes over to America, ponding up the water in the Gulf of Mexico. It has been inferred that this current is partly due to the motion of the earth, and partly to prevalent winds, those known as the Trade Winds especially driving the waters in the same direction.

The current into the Atlantic sweeps round the southern extremity of Africa by the Agulhas or Lagullas Bank, the soundings on which give mud to the westward of Cape Agulhas, and sand, containing numerous small shells, to the eastward. It might hence be assumed that this current acted upon the bank at a depth of 360 or 420 feet, sweeping off the finer sediment from the side

exposed to its force, and parting with it in the more still water behind it. A mass of water is inferred to run up the west coast of Africa, from the Cape of Good Hope (between the coast and the waters of the adjacent ocean), 60 miles wide, 1200 feet deep, and of the mean temperature of the ocean, at an average rate of one mile per hour.* There are counter currents,† and the main current is considered to extend, as regards surface, to a comparatively moderate distance from the land. As a whole, this current reminds us of a body of water in movement westward, acquiring additional velocity against the southern extremity of Africa, as any minor mass of water in movement would against a common projecting cape or headland. We may regard another great Atlantic current, the Gulf Stream, as consequent on this main current, after it has traversed the Atlantic to the West Indies. Escaping from the Gulf of Mexico, as previously noticed (p. 74), the Gulf Stream waters flow northerly, a part passing off to the eastward, after passing the Straits of Florida, probably to equalize the general levels in that direction. As to the extent and velocity of the Gulf Stream, the contradictory evidence is sufficient to show that both are occasionally much modified. The winds, by their friction, necessarily affect the course of the stream, according to their duration, strength, and direction. In mid-channel, in the meridian of Havanna, the velocity is estimated at 2½ miles per hour; off the most southern parts of Florida, and about one-third over from the Florida Reefs, at 4 miles an hour. The stream is considered to range, in the meridian of 57° W. to 42° 45′ N. in summer, and to 42° N. in winter. A reflow, or counter current, sets down by the Florida Reefs or Keys to the S.W. and W.‡

Other currents are known in the Atlantic, such as that coming out of Baffin's Bay, through Davis's Strait,§ considered to join the Gulf Stream, the united body of water crossing over to the

* Sir James Ross. Voyage in the Southern and Antarctic Regions, vol. i. p. 35.

† Close to the shore there is an eastern current. The survey of the coast of Africa, to the east of the Cape of Good Hope, was made by Captain Owen, with the assistance of this current, against the force of the trade wind. Captain Horsburgh mentions having been carried by the eastern current, on the south of the main western current, at the rate of 20 to 30 miles in the 24 hours, and, in two instances, at the rate of 60 miles in the same time.

‡ Many small vessels are stated to make their passage from the northward by the aid of this counter current.

§ This current, commonly known as the Greenland Current, sets southerly down the coast of America to Newfoundland, bringing down large icebergs beyond the Great Bank. The velocity was found, by Captains Ross and Parry, to be 3 to 4 miles per hour in Davis's Strait. Off the coast of Newfoundland, it sometimes flows at the rate of 2 miles an hour; but is much modified by winds.

coasts of Europe and Africa. A southerly flow of water takes place from the coast of Portugal towards the Canary Islands, modified by the indraught of sea into the Mediterranean. Beyond these islands a S.W. current is noticed as probably due to the influence of the N. E. trade wind.

Constant currents are also mentioned in the Pacific. Currents are described as setting off the Galapagos to the N.N.W., and at Juan Fernandez, and 300 leagues to the westward of it to the W.S.W. (16 miles per day). Great quantities of wood are drifted from the continent of America to Easter Island by a stream of water passing in that direction. Between the Sandwich Islands and the Marquesas, currents have been found flowing westward at the rate of 30 miles per day. Among the Philippine Islands a current comes from the north-east, and runs with considerable force among the passages, dividing them from each other. Various other currents in the Pacific have been noticed. There are two, however, deserving of attention, inasmuch as one, flowing northerly through Behring's Straits, is thought to proceed eastward along the north coast of America,* and the other, passes round Cape Horn to the eastward for the greater part of the year.†

In the China and India Seas we find good examples of periodical currents. The water moves from the ocean into the Red Sea from October to May, and out of that sea from May to October.‡ In the Gulf of Manar, between Ceylon and Cape Cormorin, the current flows northward from May to October, setting the remaining six months to the S.W. and S.S.W. In the S.W. monsoon, the current between the coast of Malabar and the Lakdivas sets to the S.S.E with a velocity varying from 20 to 26 miles in the 24 hours. The currents in the China Seas, at a distance from shore, commonly flow, more or less, towards the N. E. from the middle of May to the

* Kotzebue describes this current as setting through Behring's Straits with a velocity of 3 miles an hour, to the N.E.

† This current has been doubted; but as there is a prevalence of strong westerly winds round Cape Horn, during the greater part of the year, the statement that there is such a current may be considered probable. A bottle, thrown overboard by Sir James Ross, near Cape Horn, was afterwards found near Port Phillip, Australia, having passed eastward about 9000 miles in 3½ years. Allowing 1000 miles for detours, this would be a rate of about 8 miles per day. It was Sir James Ross's practice, upon throwing bottles overboard, to load all but those intended for the surface, so that they took different depths. As sand was not stated to be found in this bottle, it was inferred that it was a surface bottle; hence the winds alone had much influence on its course.

‡ A current commonly flows from the Persian Gulf towards the ocean, during the whole time that the water runs into the Red Sea, and flows into the Gulf from May to October.

middle of August, taking a contrary direction from the middle of October to March or April. Their strength is most felt, as might be anticipated, among the islands and shoals.*

With respect to temporary currents, they are found to be innumerable; severe gales of wind, of long duration, readily forcing the surface water before them. Among channels and along coasts these are chiefly felt, the two boundary shores or the single coast opposing the further rise of water, and throwing them off in the manner of tidal waves.

While considering the movement of the ocean waters, the observer should not neglect any change in their position which may be due to their relative specific gravities. Experiments upon fresh water in lakes long since showed that a body of the heaviest water, that approaching towards a temperature of about 39°·5 or 40°, remained at the bottom undisturbed,† except by the influx of river waters, charged with detritus, which forced their way, spreading mud beneath them (p. 43). The researches of Sir James Ross in the Southern Seas have shown that in a similar manner water of a certain temperature, namely, of about 39°·5 Fahr., remains at the bottom, either colder or warmer water, as the case may be, floating above it. From many observations made, it was inferred that a belt of this water of a given temperature rose to the surface in southern latitudes, of which the mean is estimated at about 56° 26′, the whole body of ocean water in that circle being of this uniform temperature from the surface to the bottom, while on the north, towards the tropics and equator, water of a higher temperature floated above it, and on the south, that of a lower temperature.‡ Thus, considering the like belt of uniform temperature to appear in such parts of

* The strongest currents in these seas are experienced along the coast of Cambodia, during the end of November. They run with a velocity of 50 to 70 miles to the southward, in the 24 hours, between Avarilla and Poolo Cecir da Terra. Some parts of the stream setting into the Straits of Malacca, cause the tide to run nine hours one way and three hours the other.

† In 1819 and 1820, the author made experiments on the Lakes of Geneva, Neuchatel, Thun, and Zug, with a view of investigating this subject. An account of these experiments was published in the "Bibliothèque Universelle" for 1819 and 1820. It was found that, in the Lake of Geneva, the water, in September and October, 1819, had a temperature of 64° to 67° Fahr., from the surface to the depth of 1 or 5 fathoms, and that there was a general diminution of temperature downwards to 40 fathoms. From 40 to 90 fathoms, the temperature was always 44°, with one exception, when it was 45° at 40 fathoms. From 90 fathoms to the greatest depths, which amounted to 164 fathoms, between Evian and Ouchy, the temperature was invariably 43°·5. After the severe winter of 1819-20, the same temperature continued beneath. Experiments on the Lakes of Neuchatel, Thun, and Zug, alike pointed to water of a temperature approaching to the greatest density of water, between 39° and 40°, being at the bottom.

‡ The following were the observations on which Sir James Ross founded his view of

the northern hemisphere as is covered by the ocean,* there would be, where land did not occur, three great thermic basins, two towards each pole of the earth, and a middle trough, or belt through the central part of which the equator would pass. Sir James Ross points out that in lat. 45° S., the temperature of 39°·5 has descended to 600 fathoms, increasing in depth in the equatorial and tropical regions to about 1200 fathoms, the temperature of the surface in the latter being about 78°.† On the south of the belt of uniform temperature, the line of 39°·5 is considered to descend to 750 fathoms in lat. 70°, the surface being there at 30° Fahr.

To estimate a movement which might be produced by the settlement of any water of the density of 39°·5, striving to occupy an equal depth beneath those of inferior weight, either of greater or less temperature, as the case might be, to the north and south of these belts of uniform temperature, supposing that some approximation to such a belt was to be found in the northern hemisphere, we should compare the distance from these belts with the depths at which given temperatures have been observed. This done, we obtain for the slope on either side of the southern belt (assuming a plane for more ready illustration) of about 1 in 1723 to the 1200 fathoms of 39°·5 beneath the equator, and of about 1 in 1136 to the same temperature beneath 750 fathoms in 70° south latitude. So small an angle, with a change of temperature so gradual, could scarcely be expected to produce a lateral movement in the mass of ocean waters of geological importance.‡

the position of this circle, the water being ascertained in the localities noticed to have the same temperature from the surface downwards:—

Latitude.	Longitude.
57° 52′ S.	170° 30′ E.
55 09	132 20
55 18	149 20 W.
58 36	104 40
54 41	55 12
55 48	54 40

Voyage to Southern and Antarctic Regions, vol. ii.

* Allowing the same causes to be in operation in the northern hemisphere, we should expect similar effects, however modified by local circumstances. Scoresby obtained, in lat. 79° 4′ N., long. 5° 4′ E., 36° at 400 fathoms, the temperature increasing from 29° at the surface. Another observation by the same author, in lat. 79° 4′ N., gave 37° at 730 fathoms, the surface being 29°. Again, in lat. 78° 2′ N. and long. 0° 10′ W., he found 38° at 761 fathoms, the surface being 32°.

† With regard to observations in the tropics, Colonel Sabine found, in lat. 20° 30′ N., and long. 83° 30′ W., a temperature of 45°·5 at 1000 fathoms, the surface water being at 83°. Captain Wauchope obtained in lat. 10° N., and long. 25° W., 51° at 966 fathoms, the surface water being at 80°; and he also found in lat. 3° 20′ S., and long. 7° 39′ E., a temperature of 42° at 1300 fathoms, the surface water being at 73°.

‡ It should be remarked that the temperature of 39°·5, found by Sir James Ross in situations leading to the inference that such temperature is that of the greatest

The agency of ocean currents in the transport of matter mechanically suspended in their waters, and derived from the decomposition or abrasion of land, will necessarily depend upon local conditions. Here and there streams of tide may deliver such matter to them, to be borne in the direction in which they may move, and great rivers, such as the Yang-tse-kiang, the Ganges, the Indus, the Quorra, and the Amazons, may thrust out bodies of water, flowing beyond the return of the tidal streams off coasts, and carrying detritus to ocean currents, through which it would have gradually to descend. It might thus be transported long distances, particularly if the depths it might have to descend, before stagnation of the lower waters would prevent any than a vertical fall of the matter, were considerable.* The matter obtained from the land seems chiefly to be thrown down as a fringe of various shapes and composition, skirting the shores; sometimes, from local conditions, extending to far greater distances than at others.

Although the great floor of the ocean may not be very materially

---

density of sea water, containing the ordinary amount and kinds of salts in solution, does not well accord with experiments in the laboratory. According to Dr. Marcet, those made by him show that the maximum density of sea water is not at 40° Fahr. In four experiments, Dr. Marcet cooled sea water down to between 18° and 19°, and found that it decreased in bulk till it reached 22°, after which it expanded a little, and continued to do so until the water was reduced to 19° and 18°, when it suddenly expanded and became ice at 28°. According to M. Erman, also, salt water of the specific gravity of 1·027 diminishes in volume down to 25°, not reaching its maximum density until congelation.

These results would seem to point either to some modifying influence acting upon the waters of the ocean, to faults in the instruments, to the mode of employing them, or to sources of error in the laboratory experiments not suspected. At considerable depths, the heavy pressure upon the bulbs of the thermometers, if used naked, might be supposed to produce an error as to the mass of water of uniform temperature from the surface downwards. If pressure, however, upon the bulb caused a higher apparent temperature, this should vary with such pressure; but the results do not bear out this view, unless it be assumed that the gradual increase of pressure exactly counterbalanced a decrease of temperature. It is worthy of remark, that the temperature of 39°·5 is about that assigned, from experiments, to pure water. It may be here observed that the water beneath 90 fathoms in the Lake of Geneva was found, both after a warm summer and a severe winter, to remain at 43°·5, not 39°·5 or 40°, as experiments in the laboratory would lead us to expect. From observations on the temperature of the western Mediterranean waters, at various depths, it is inferred that all beneath 200 fathoms remains at a constant temperature of about 55°. (D'Urville, Bul. de la Soc. de Geographie, t. xvii. p. 82.)

If we take 39°·5 for the temperature of the greatest density of sea water, we shall have to consider that the salts in solution produce no influence upon such density, the water alone having to be regarded. It would be very desirable that experiments respecting the density of sea water at different temperatures should be repeated in the laboratory, and that observations should be made at different seasons upon the temperature of deep fresh-water lakes, in order to see if we are in any way to regard the temperature obtained in the sea of 39°·5, observed by Sir James Ross, as a result to which some modifying influence may be attributed.

* Some very interesting observations respecting the surface density of the sea off the coast of British Guiana were made by Dr. Davy (Jameson's "Edinburgh

covered by deposits from ocean currents, conveying detritus from the great continents, Australia, and the larger islands of the world, the oceanic islands may collectively furnish matter of importance. The observer will find that many of these islands rise from comparatively considerable depths, so that detrital matter derived from them by the action of breakers (and they are very commonly exposed to a nearly-constant abrasion by the surf), moved by the tidal waves sweeping by the islands, and thence delivered into any ocean currents passing near, may be carried by the latter to considerable distances. These oceanic islands are found to be chiefly of two kinds, the one of igneous, the other of animal origin. With respect to the former, we have not only to consider the detritus they may now furnish by the action of breakers upon them, but also the transportable matter which may have been ejected from the igneous vents while they rose, by the accumulation of molten rock, cinders, and ashes.

Instead of simply accumulating around the igneous vent, as would happen, with certain modifications from the distribution of wind-borne ashes and small local movements of water in tideless seas, not only might there be a to-and-fro distribution of the volcanic matter carried various distances in mechanical suspension from the tidal wave acting against the new obstacle to its movement, but the finer substances could also be borne away by any ocean current passing near, and thus such substances be carried far onward in the direction of its course. As soon as any igneous matter is raised above the sea level, so soon is it attacked by the breakers, and only

Journal," vol. xliv, p. 43, 1848). He found that where the Demerara river meets the sea, near George Town, the density of the water was 1·0036, and subsequently as follows:—

1.	11 miles off shore =	·0210
2.	19	·0236
3.	27	·0250
4.	35	·0236
5.	43	·0250
6.	51	·0258
7.	80	·0266

The specific gravities of Nos. 4 and 5 were considered to have been influenced by heavy showers of rain which fell while the steamer on which Dr. Davy was on board passed. This modification in the density of the surface waters, by tropical rains, is well shown by the observations of the same author, off Antigua and Barbadoes. Towards the end of a very dry season, the specific gravity of the surface water, off the former, was found to be 1·0273, while, after three months of heavy rains, off Barbadoes, the specific gravity was reduced to 1·0260. The positions of these two islands give such observations considerable value. With respect to the matter mechanically held in suspension in the waters off British Guiana, Dr. Davy states that, for many miles near the land, it was sufficient to give a light-brown tint to the sea, like the Thames at London-bridge. It was only at about the distance of 80 miles from shore that the waters presented the blue colour of the ocean.

in proportion to its solidity and mass can the portion above water, and removed from the destructive action of the surf, remain to be more slowly wasted by atmospheric influences, and to be clothed with vegetation, if within climates fitted for its growth. Many an island in the ocean can be regarded as little else than the higher part or parts of a volcano, or some more extended system of volcanic vents, rising above its level, the mass and kind of matter ejected being sufficient to keep it there. As might be expected in a great volcanic region like that of Iceland, igneous vents have opened in the sea near its shores, as well as upon the dry land. A volcanic eruption is recorded as having taken place in 1783, about 30 miles from Cape Reikianes, and another off the same island about 1830.* In 1811 a volcanic eruption was effected through the sea off St. Michaels, Azores, and eventually, after the ejection of much matter, columns of black cinders being thrown to the height of 700 and 800 feet, an island was formed, about 300 feet high, and about one mile in circumference.

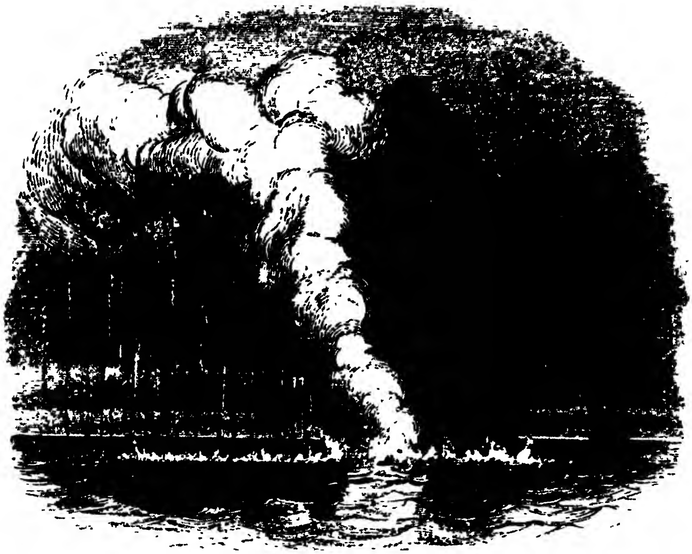
Fortunately the formation of this island was observed and recorded. It was first discovered rising above the sea on the 13th June, 1811, and on the 17th was observed by Captain Tillard, commanding the "Sabrina" frigate, from the nearest cliff of St. Michaels. The volcanic bursts were described as resembling a mixed discharge of cannon and musketry, and were accompanied by a great abundance of lightning. The following (fig. 67) was a sketch made at the time, and will well illustrate the manner in which ashes and lapilli may be thrown into any ocean current or tidal stream passing along, and be borne away by it.

This island, to which the name of Captain Tillard's frigate was assigned, subsequently disappeared, but whether simply by the action of the breakers alone, or from the subsidence of the main mass beneath, or from both causes, accounts do not enable us to judge.†

* In 1783, the eruptions of several islands were observed as if raised from beneath, and, during some months, vast quantities of pumice and light slags were washed on shore. "In the beginning of June, earthquakes shook the whole of Iceland; the flames in the sea disappeared, and a dreadful eruption commenced from the Shaptar Yokul, which is nearly 200 miles distant from the spot where the marine eruption took place."—(Sir George Mackenzie's Travels in Iceland.)

† This is not the only instance of a volcanic eruption forming a temporary island above the sea-level among the Western Islands. It is recorded in the MS. Journals of the Royal Society (a collection containing a mass of curious information respecting the progress of science after the foundation of the Royal Society), that Sir H. Sheres informed a meeting, of January 7th, 1690-91, "That his father, passing by the Western Islands, went on shore on an island that had been newly thrown up by a volcano, but that in a month or less it dissolved, and sunk into the sea, and is now no more to be found.

Fig. 67.



No doubt very many of the supposed banks in the ocean upon which the surf is stated to have been seen breaking, and never afterwards found, may be very imaginary, but it is still possible, that here and there statements of this kind may be founded upon more positive evidence; and that, making all allowance for incorrect views as to the latitude and longitude of the supposed banks, some due to the upraising of volcanic cinders and ashes have been observed, these finally so cut away that the sea no longer broke over them. However this may be, we can scarcely suppose that over the floor of the ocean all the eruptions from every volcanic vent upon it have reached above the surface of the water and remained there as islands, or that some, which have accumulated matter to depths not far beneath the surface waters, may not occasionally so vomit forth cinders and ashes, that these substances remain for a time above water until removed by the influence of breakers.

CHAPTER VII.

CHEMICAL DEPOSITS IN SEAS.—DEPOSITS IN THE CASPIAN AND INLAND SEAS.—CALCAREOUS DEPOSITS.—FORMATION OF OOLITIC ROCKS.—SALTS IN SEA WATER.—CHEMICAL DEPOSITS NOT NECESSARILY HORIZONTAL.

WE have previously adverted to the mixed deposits of calcareous and sedimentary matter in tideless or nearly tideless seas, from which alternate layers of argillaceous limestones and clays, or lines of argillaceous limestone nodules in the latter might result. According to the specific gravities of the waters of such seas, arising from the different amount of matter in solution in them, will, as we have seen, depend the distances over which river waters can flow outwards, supposing such rivers, for illustration, to be equal in volume and velocity, and as respects the amount of matter in solution or mechanically suspended. In this respect, the Caspian, the Black, and the Baltic Seas would all differ, the latter most approaching in the character of its waters to a fresh-water lake. Comparatively, these bodies of water would appear to afford greater tranquillity than tidal seas for the production of chemical deposits, always allowing for the depths to which their waters may be disturbed by surface causes, such as winds and changes in atmospheric temperature.

In tideless seas, such as the Caspian, where the substances brought down in solution by the rivers accumulate in comparatively still water, we should expect deposits which could not be effected with equal facility in the ocean, even in those parts which adjoin coasts. In the one case, evaporation keeps down the body of the water, probably even diminishing its volume during a long lapse of time; while, in the other, these solutions enter the great mass of ocean waters, and become so lost in it, that certain of them may only, under very favourable conditions, be able to accumulate as a coating or bed upon any previously-formed portion of the ocean floor. The way in which the tidal wave thrusts back river waters twice in each day (taking the subject in its generality),

mingling the common sea waters with those of rivers, up the estuaries, is alone a marked difference from the outpouring of the rivers, with their contained solutions unmixed until the river waters flow over the sea. Instead of comparative quiet along-shore, except where disturbed by the action of surface waves, the whole body of water along tidal coasts is kept in motion, moving alternately one way or the reverse, and not unfrequently in various directions, in consequence of the modification of the bottom, and the mode in which the tidal wave may strike variously-formed or combined masses of dry land.

We have above called attention to the differences in tideless or nearly tideless seas, arising from differences between the evaporation of their surfaces, and their average supply of water from rivers or rains. Not only should we thence expect the modification of sedimentary deposits previously mentioned, but modifications also in the chemical coatings. An isolated area, like the Caspian, if the evaporation of its waters be greater than its supply, may, during such decrease, present us with conditions favourable to a deposit of some of its salts, while the main mass of the waters may yet be well able to hold much saline matter in solution. Any shallow parts adjoining the shores becoming isolated, and therefore cut off from the river supplies afforded to the main body, may readily be deprived of all their water by evaporation, and a sheet of saline matter be the result. Indeed, in this manner, any substances in solution would become deposited, and how far they might remain exposed without being removed by atmospheric influences, would depend upon the climate of the locality. That any such beds, the result of the evaporation supposed, may be covered by ordinary sedimentary deposits, due to geological changes of the locality, will be obvious.

Around such bodies of water as the Caspian, the observer possesses good opportunities for studying subjects of this kind, which are of considerable interest geologically, when we consider the mode of occurrence of gypsum and rock-salt in many situations, the not unfrequent connexion of these substances, and the kinds of sedimentary matter with which they are often associated. It may be also deserving of attention to consider in such parts of the world the probable annual evaporation of the surface of seas like the Caspian, and the annual supply of waters from rivers and rain.*

* It is interesting to consider, in any given land where such bodies of water may be found, even though of much less size, and where it seems certain, from geological evidence, that the present area occupied by such waters is less than formerly, how far

It may have happened from geological changes, such as might readily convert the Persian Gulf into an isolated sea, by raising the bottom between Cape Mussendom and the opposite coasts at Grou and Sereek, or the Red Sea, into another, by raising the bottom at Bab-el Mandeb, that these masses of water no longer communicated with the main ocean. Looking at the climatal conditions, and the absence of any great drainage from adjoining land flowing into it, the Red Sea would lose its waters from evaporation, while with respect to those of the Persian Gulf, it would depend upon the difference between the evaporation and supply of water chiefly obtained from the Euphrates, Tigris, and their tributaries. From existing information, we should anticipate that this supply would not equal the evaporation, so that both bodies of water might become Caspians.

It would be well if observers, when among such parts of the world, would gather information sufficient to show us the probable results of such alteration of conditions, especially as respects the deposits of substances now in solution in these seas, and their intermixture with common detrital matter. Observations directed to such points can scarcely fail to be valuable with respect to geological theory. Under the supposition of the conversion of the Red Sea into a Caspian, not only might there be a mixture, under favourable conditions, of chemical deposits and detrital accumulations, but coral banks and reefs would be also included in them.

By a glance at a map of Asia, it will be seen that a very large area, extending along 70 degrees of longitude from the Black Sea into China, with a varied breadth of 15 to 20 degrees of latitude, does not drain directly or indirectly into the ocean. There is reason to believe that it is a mass of land which, from geological changes, has been cut off from such drainage, the Caspian, the Sea of Aral, with numerous smaller bodies of water, now receiving such drainage waters as evaporation from the surface of this great area will permit, when gathered together in different positions.

the climatal conditions may so influence the evaporation and supply of water that a kind of balance is established. We may, for illustration, suppose that, in the first place, the climatal conditions are such, after the separation of a mass of sea waters from connexion with the ocean, that a considerable diminution of the volume of the separated water, and consequently, in all probability, of the area occupied by it, takes place. Then will arise the local conditions, under which this diminution may either continue or a balance of evaporation and supply become established. Evaporation, all other things being equal, will depend upon the area of water exposed. If large rivers, such as the Volga, for example, entering the Caspian, bring much sediment into the sea or lake, they tend to make it shallow, and also, by their deltas, to diminish the area, so that the conditions, as to general area, depth, and consequent volume of the water, alter. This alone might destroy any balanced conditions.

The evaporation may completely overpower the supply of water in certain parts of such an area, the salts in solution in the pre-existing waters forming sheets of matter corresponding with the minor areas or lakes when such solutions became in a condition to permit deposits, the least soluble substances being the first thrown down. A deposit of a particular substance once effected, similar matter would be more readily withdrawn from the solution by the attraction of the first deposits of such substance. In a dry climate, such portion of the common detritus, as did not become consolidated, would be swept about by the winds, forming deserts, such as we find in the region noticed, the great Chinese desert of Kobi, or Shamo, being the largest of them. In all such lands the explorer will not lose his time by carefully examining the shores of these various inland seas and lakes, observing the physical conditions which may produce the isolation of shallow parts. It would be well also to study deposits of saline matter with reference to their origin from conditions, which may have readily obtained, in consequence of geological changes, by the separation of shallow-water indentations fringing the ocean, particularly in warm and dry climates,* as well as by the partial or total evaporation of salt lakes.

Amid the great flats which here and there occur on the shores of tidal seas, and which may become dry at certain times, so that patches of sea-water irregularly scattered over them are evaporated, leaving the salt, we have no doubt conditions, particularly in dry and warm climates, for the accumulation of thin sheets of salt, or other substances in solution, which, under favourable circumstances, might be covered up, and, to a certain extent, be preserved by detrital mud; but these deposits would scarcely have the importance of those previously noticed. At the same time, such situations should be examined with reference to the chemical accumulations which may be thus intermingled with detrital matter.

* In all cases, where practicable, it is desirable to obtain information as to the matters in solution in the various inland seas and lakes. They are known to differ in this respect, as might be anticipated. Thus, according to M. Eichwald, the waters of the Caspian contain much sulphate of magnesia, in addition to the other salts held in solution. Those who are possessed of sufficient chemical knowledge, if they have with them any of the little portable chests of the needful substances and apparatus, will have a local means of a qualitative analysis. It would be well if they could perform a quantitative one on the spot, seeing the difficulty of conveying bottles of water, to be kept, perhaps, a long time, and amid high temperatures. When the observer may not be a chemist, he may still assist, under favourable conditions as to transport, by obtaining the waters and putting a sufficient quantity into a clean bottle, immediately sealing it up carefully and tight, and forwarding it, as soon as circumstances may permit, to some experienced chemist for examination.

With respect to deposits from chemical solution, the calcareous may be considered as the most important geologically. We have previously adverted to their production in the air, and in fresh-water lakes. The cases of consolidated beaches on some coasts, like those noticed in Asia Minor, may be regarded as in a great measure due to the evaporation of the water containing the bicarbonate of lime in solution, as it percolates through these beaches. In the same manner, we seem to obtain their consolidation in some places by the oxides of iron and manganese, and by other substances. Respecting the actual formation of beds of limestone in the deeper sea by chemical deposit alone, though we feel assured that it is effected, the exact manner is scarcely yet well determined. The rivers flowing into both tideless and tidal seas alike transport calcareous matter in solution into them, though very variably; in scarcely appreciable proportions in some, abundantly in others. So long as the carbonic acid needful for the solution of the carbonate of lime remains, the latter will continue in the waters, but should it be withdrawn, either by evaporation of the sea waters in shallow places, or by separation in any other way, the carbonate of lime, if the lime be not taken up in any other combination, will be deposited.

With regard to shallow situations in tidal seas, particularly in warm climates, and where pools of water are left for sufficient time at neap tides, we should expect an evaporation of the water, at least in part, and a loss of the carbonic acid, enabling any carbonate of lime present to be held in solution, so that there was a consequent deposit of calcareous matter. This may be well seen where waters highly charged with bicarbonate of lime flow slowly into some nook or bay, on tropical coasts, and even in localities where the rise and fall of tide is small, as, for instance, around Jamaica. It is in such situations, under favourable conditions, that the little grains termed oolites, formed of concentric coatings of calcareous matter, may be sometimes observed to form. A slight to-and-fro motion, produced by gentle ripples of water, may occasionally be seen to keep the carbonate of lime depositing in movement and divided into minute portions, so that instead of a continuous coating of calcareous matter upon any solid substances beneath, a multitude of these little grains is produced. As might readily be anticipated, a small fragment of shell and even a minute crystal of carbonate of lime is sufficient to form a nucleus for the concentric coatings of these oolitic grains. An observer would do well, when an opportunity of this kind may present itself, to watch the mode in which the grains may be

mechanically accumulated, like any other grains of matter, by the wash of the sea, or the drift caused by tidal streams, as he will thereby be the better enabled to judge of the differences or resemblances he may find between these accumulations and the beds formed of oolitic grains in the calcareous deposits of various geological ages.

While the mode in which calcareous matter may be deposited on the shores of seas may thus be advantageously studied, that in which it is effected in deep water must necessarily be matter of inference. By the means previously noticed, a large collective amount of carbonate of lime, held in solution by the needful addition of carbonic acid, is discharged by rivers into the sea; more, no doubt, in some localities than in others, but still as a whole, somewhat widely. Although we might expect solutions of a great variety of substances in the sea, the drainage of the land supplying them constantly, our knowledge on this subject would be more advanced than it is at present, if waters were more collected in different parts of the world, and off a variety of coasts, than they have been.

According to Professor Forchhammer, the greatest amount of saline matter in the Atlantic Ocean is found in the tropics far from land, in such places the sea-water containing 3·66 parts of saline matter in 100. He states, that the quantity diminishes in approaching the coasts, on account of the rivers pouring their waters into the sea, and that it also diminishes on the most western part of the Gulf Stream, where the proportion is 3·59 per cent. Professor Forchhammer proceeds to observe, that by the evaporation of the Gulf Stream waters, the quantity of saline matter increases towards the east, and reaches 3·65 per cent., in N. lat. 39° 39′ and W. long. 55° 16′. Thence it decreases slowly towards the N E.; and at a distance of 60 to 80 miles from the western shores of England, the Atlantic contains 3·57 per cent. of solid substances in solution. The same proportion of salts is found all over the north-eastern part of the Atlantic, as far north as Iceland, at distances from the land not effected by the outflow of rivers.*

* It is desirable that in all researches as to the amount of the saline contents of the ocean, the depth from which waters for examination may be taken, be regarded. With respect to the specific gravity of sea water at different depths, Sir James Ross mentions (Voyage of Discovery and Research in the Southern and Antarctic Regions), that in lat. 39° 16′ S. and long. 177° 2′ W. (there being no bottom at 3,600 feet), the specific gravity at the surface was 1·0274; at 900 feet, 1·0272; and at 2,700 feet, 1·0268, all ascertained at 60° Fahrenheit. He further states that his daily experience gave this diminished kind of specific gravity in the depths. As evaporation would tend to render the surface waters more saline, it may be deserving of attention how far this cause may operate downwards in the sea.

With respect to the chemical character of the saline substances in the waters of the Atlantic, it would appear that they do not differ so much as might be supposed. At the same time, Professor Forchhammer's researches lead him to consider that lime is rather rare around the West India Islands, where myriads of polyps employ it for their solid coral structures; the proportion of lime to chlorine being there as 247 to 10,000, while the same substance is more common in the Kattegat, where part of the lime brought by numerous rivers into the Baltic is carried to the ocean. In the Kattegat the proportion of lime to chlorine is as 371 to 10,000. In the Atlantic Ocean 17 analyses gave 297 to 10,000; and between Faroe and Greenland 18 analyses afforded 300 to 10,000.*

Researches of this kind, limited as they are at present, are still sufficient to point out the modifying influences of proximity to land, of the heat of the tropics, of the melting of ice in the polar regions, and of oceanic currents flowing from one region, where certain conditions prevail, to another where these may be modified.

As geologists, we have to inquire if the salts in solution, and derived by means of rivers from the land, are thrown down on the sea-floor, either within a moderate distance from the land, or further removed in deeper oceanic waters. If we take the calcareous matter, we find that it can be transported, by means of rivers flowing outwards, for various distances over the heavier sea waters, to be still further carried outwards and into greater depths of water, probably, if an ocean current seizes on the river waters thus situated. No small aid would be afforded if, when fitting opportunities presented themselves, waters from the streams which might thus be traversed were carefully examined with reference to their chemical character. In warm climates there might be much evaporation from the upper part of river waters thus slowly passing along the surface of the seas, productive of results, as regards matter in solution, of appreciable value.

When we consult analyses of sea waters, to ascertain the condition in which lime may be present in them, we find enough to show that much is to be learnt by experiments made with the aid which the present methods of analysis can afford. We can readily understand that while lime may be pouring into some parts of the ocean, as a bicarbonate kept in solution by the proper amount of carbonic acid, it might be converted into solid matter by animal life in another, in regions where a balance of supply is not kept up, so

* Forchammer. Memoirs of the British Association for the Advancement of Science, vol. xv. p. 90.

that eventually very unequal quantities are distributed in solution. But it would be well to ascertain such facts carefully, and especially with reference to the combination in which the lime may be found in the different regions of the ocean.*

With respect to the deposit of carbonate of lime from sea waters, Dr. Lyon Playfair suggests that, as river waters generally contain in solution a small quantity of silicate of potash, the carbonic acid, dissolved in sea water, enabling the carbonate of lime to be therein held in solution, would act on this silicate, decomposing it, and forming a carbonate of potash. The solvent being thus removed from the carbonate of lime, the latter would be precipitated, and a new portion would be formed from the double decomposition of the newly-formed carbonate of potash on the sulphate of lime and chloride of calcium when present. He suggests that this process of decomposition may account for the silica so frequently found in limestones. It is, however, to the action of vegetation, where this can flourish, on sea waters, that Dr. Lyon Playfair attributes a more general deposit of any carbonate of lime from them. He remarks, that marine, like terrestrial plants, constantly require and take away carbonic acid from the waters around them, so that the quantity necessary to keep any carbonate of lime in solution, and which may find its way into the sea waters, being removed, the carbonate of lime is thrown down.

Independently of the soluble matter thrown into the sea by rivers returning to it frequently that which in anterior geological times was accumulated in it, we have to reflect that the volcanic action which we know has been set up upon the ocean-floor, sometimes throwing up matter above the surface of the sea, forming islands, must as a whole have caused no small amount of soluble matter to be vomited forth. Looking at the gases evolved and substances sublimed from sub-aërial volcanos, we should expect many combi-

---

* We are indebted to Schweitzer for a very careful analysis of the waters of the English Channel. No doubt it is only good for the locality, one not favourable for a knowledge of the composition of oceanic waters, being too much shut in by land, from which river waters, differently charged with saline matter, are discharged. His analysis is as follows:-

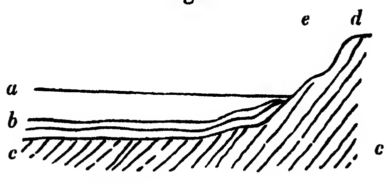
Water - - - - - -	964·74372
Chloride of Sodium - -	27·05948
,, Potassium - -	0·76552
,, Magnesium - -	3·66658
Bromide of Magnesium - -	0·2929
Sulphate of Magnesia - -	2·29578
,, Lime - - -	1·40662
Carbonate of Lime - - -	0·03301

With, in addition to these constituents, distinct traces of iodine and ammonia.

nations to be formed and decompositions to arise. Seeing also the soundings around certain oceanic and volcanic islands, no slight pressure would have been exerted upon the earlier volcanic action beneath the seas, a modifying influence alone of no slight importance. Surrounded by seas of inferior temperature, closing in upon the volcanic vent as the heated waters rose upwards, there would be a tendency to have certain substances, only soluble at a high temperature, thrown down where the cooling influences could be felt; as also, when these substances may be borne upwards by the heated waters, to have them distributed by any oceanic currents acting over the locality, supposing that the heated waters either rose to, or were produced at distances beneath the surface of the sea where these currents could be felt. Without entering further upon this subject, we would merely desire to point out that, in volcanic regions, the sea may not only receive saline solutions marked by the presence of certain substances not so commonly thrown into it by rivers elsewhere, but that also submarine volcanic action may be effective in producing chemical deposits, either directly, or indirectly, which, under ordinary conditions, would either not be formed, or not so abundantly.*

With regard to the mode in which chemical deposits may be accumulated, it is very needful to consider that horizontality is not essential to them. They may be formed at considerable angles, against any previously-existing surface offering the needful conditions. Numerous deposits from solutions are effected as well on the sides as on the bottoms of vessels containing them.† Hence we may have deposits on the large scale, giving rise to deceptive appearances. Let *a*, for example, in the annexed section (fig. 68)

Fig. 68.



be the surface of a fluid, such as the sea, from which the beds, *b*, have been deposited from chemical solution (limestones for instance)

---

* It would be very desirable to ascertain points of this kind, so far as examining the sea waters around volcanic regions may enable the observer to do so; and more especially when, by any fortunate chance, opportunities are afforded after any submarine volcanic action may be evident or supposed.

† Pipes conveying waters containing much bicarbonate of lime, or many other substances in solution, are well known to be often coated all round.

upon the pre-existing surface, *c d*, of a stratified rock, *c c*, and it might, if only a portion of such a section was subsequently exposed, be concluded that there had been movements of the land tilting up these beds at *e*, when in reality there has been perfect repose as regards their relative position, since the time of their deposit. Even when, as a whole, somewhat horizontal accumulations of this kind might be expected, they are often found to have moulded themselves upon the irregularities of ground upon which they were thrown down.

CHAPTER VIII.

PRESERVATION OF REMAINS OF EXISTING LIFE AMID MINERAL MATTER.—OF PLANTS AND VEGETABLE MATTER.—BOGS.—DISMAL SWAMP.—RAFTS IN THE MISSISSIPPI.—ANIMAL REMAINS—ON THE LAND.—VERTEBRATA.—OSSIFEROUS CAVERNS AND LAKE DEPOSITS.—INSECTS.—LAND MOLLUSCS.—EFFECTS OF SHOWERS OF VOLCANIC ASHES.—ESTUARY DEPOSITS.—FOOTPRINTS ON MUD.

THIS is a subject of much importance to the geologist desirous of reasoning correctly upon the mode in which the fossiliferous rocks may have been accumulated. The habits of plants and animals engage the attention of the naturalist, and by his aid most important benefits are conferred upon the geologist. He is thus enabled to infer how plants or animals, found existing under certain conditions, may contribute by their remains to the mass of mineral accumulations now taking place, these occasionally even forming thick beds, spread over considerable areas, without the admixture of mud, and sometimes of any sediment derived from the decomposition or mechanical destruction of previously-existing rocks.

The observer should, in the first place, direct his attention to the manner in which the remains of terrestrial life may be entombed. Though when terrestrial plants die, the substances of which they are composed are, as a mass, returned to the atmosphere and soil whence they have been derived, the movements of animals which may feed upon them being regarded as so far local, that keeping to the grounds where their food is presented to them, their droppings restore to the soil what the plants had removed from it, the carnivorous animals which consume the graminivorous, returning that which the latter did not prior to death,—there are still conditions under which parts of existing vegetation may become permanently preserved.

Exposed to atmospheric influences after death, vegetation decays according to the structure of the different plants and the climate of

the locality. The rapidity with which decomposition is effected in certain tropical regions is well worthy of attention. We not unfrequently find the outside of a large and prostrate tree retaining its form, and while the whole of the inside is hollow, filled with leaves that have fallen into it, and teems with animal life. This kind of decay is still more instructive when upright stems of plants, in tropical low grounds, liable to floods, retain their outside portions sufficiently long to have their inside hollows partially or wholly filled with leaves and mud or sand, the whole low ground silting up, so that sands, silt, and mud accumulate around these stems, entombing them in upright positions, without tops, though their roots retain their original extension. The study of the sedimentary accumulations of river deltas, amid the rank vegetation of some tropical countries, is very valuable as respects certain deposits in which the remains of vegetation form a conspicuous and important portion. Behind mangrove swamps much that has a geological bearing may be frequently seen; and indeed amid them, the observer not forgetting to direct his attention to the mode in which animal as well as vegetable remains become mingled with, and finally covered over by, sedimentary matter.

Not only in the tropics, but in other regions, large tracts of marsh land, interspersed with shallow lakes, are highly favourable to the accumulation of vegetable substances. The leaves of trees, growing in such situations, falling upon the patches of water, take a horizontal position, spreading in a layer in certain climates and seasons over their surfaces. These leaves gradually soak up water, and sink to the bottom. If, from time to time, flood waters bring fine mineral matter in mechanical suspension into such situations, it settles, and thus the leaves become preserved in thin layers alternating with the clayey sediment. Should it so happen that waters, charged with calcareous matter in solution, find their way either gradually and constantly, or by sudden rushes in floods, we may have the leaves or other remains of plants preserved in a deposit of carbonate of lime, more or less pure, according to the presence of any other matter brought into the lakes in mechanical suspension or chemical solution.

The manner in which bogs are formed should also be studied. Many no longer exhibit their progress over shallow lakes, while others will show it. In the latter case we find aquatic plants, like the large rushes and water lilies, accumulating mud about their roots, as also decaying vegetation, upon which finally the bog

plants advance, the chief of which, in our climate, is the *Sphagnum palustre*. As these decay beneath, a new growth continues above, up to levels where the requisite moisture can be obtained.* Trees are very frequently seen in these bogs (some of which are very extensive), in a manner showing that the conditions favourable for the growth of various trees have from time to time obtained, so that distinct levels of them have been found occasionally in the same bog.

The extent of bogs is very variable, as also the bottoms on which they repose. Sometimes the latter are formed of shell marls, accumulated at the bottoms of the shallow lakes, anterior to the advance of the aquatic vegetation over them. The thickness of bogs necessarily varies: in some 10 to 30 or 40 feet is not uncommon. Of the pauses in the accumulation of bogs, sufficient to permit a growth of trees upon them, as also a surface upon which habitations may be constructed, perhaps as good an example as any is that of the ancient wooden house discovered in June, 1833, in Drumkelin Bog, on the north-east of Donegal. It was 16 feet below the surface of the bog before the upper part was taken off, and 4 feet beneath the cuttings of the time, standing itself upon 15 feet more of bog, so that the total thickness at that place had been 31 feet. The house itself was a square of 12 feet sides, and 9 feet high, and was formed of two floors, the roof constructed with thick planks of oak, the wood employed for the whole dwelling, upon which no iron had been used. Upon clearing away the bog from the level of the house, a paved pathway was discovered extending several yards from it to a hearthstone, covered with ashes, some bushels of half-burned charcoal, some nut-shells, and blocks of wood partly burned. Near the house there were stumps of oak trees, which grew at the time it was inhabited. A layer of sand had been spread over the ground before the erection of the house. All seems to have marked a state of repose in the growth of this part of the bog; so that a change of conditions affecting the drainage would seem needful to account for the accumulation of 16 feet more above the surface, after the time when this wooden house was constructed. It may have been that one of those burstings of parts of a bog,

* Those travelling in North Wales will find, opposite Cwm-y-glo, below the bridge crossing the outlet of Llyn-Padarn (the lower Llanberis lake), a good example of a lake filling up, with the advance of water lilies and other aquatic plants upon a still remaining portion, while bog plants and bog creep on behind them. At the proper season, the locality is brilliant with thousands of water lilies thus advancing. It is easy to see that this was once a third Llanberis lake, but, being shallow, was the first to be nearly filled up.

some of which are recorded, had overwhelmed this locality, soft boggy matter having gradually accumulated to a higher level under favourable circumstances in some place adjacent.

Bogs are very irregularly dispersed, forming unequal patches as to area and thickness. The surface occupied by the bogs of Ireland alone, has been estimated at 2,800,000 acres. From the humic acid in them, animal and vegetable substances are often found well preserved, and, in consequence, numerous relics of ancient times have been handed down to us, which, unless entombed in bogs, would have remained unknown. Other things have evidently been lost in them, and have been brought to light by the progress of the turf-cutter. Many of the beautiful bronze swords, spear-heads, and other ornaments and weapons of its ancient inhabitants, have been thus preserved in Ireland. As might be expected, also, the remains of animals are found which have perished in the bogs.

Of bog-like accumulations in a warm climate, the "Dismal Swamp," as it is called—40 miles long, from north to south, and 25 miles in its greatest breadth, from east to west—partly in the State of Virginia and partly in North Carolina, seems an excellent example. Sir Charles Lyell describes this swamp as "one vast quagmire, soft and muddy, except where the surface is rendered partially firm by a covering of vegetables and their matted roots."* From the nature of the mass, which appears to be chiefly formed of vegetable matter, spongy for the most part, logs and branches of trees intermingled in it, water is so disseminated that the central portions of the swamp are the highest, rising on all sides above the surrounding firm and dry land, except for about 12 or 15 miles on the western side, where rivers flow into it from more elevated ground. The greatest height of the central part above the sides is estimated at about 12 feet, and in such central portion there is a lake, 7 miles long and 5 miles wide. The greatest depth of this lake is 15 feet; the sides are composed of steep banks of the vegetable mass, and the bottom is chiefly formed of the same matter in a highly-comminuted state, with sometimes a white sand, about a foot thick. Rivers flow out of the swamp from all other parts of its margin except that mentioned.

It is a highly-interesting fact as connected with this swamp, one having many geological bearings, pointed out by Sir Charles Lyell, that the surface supports a growth even of trees. He mentions

* Lyell's Travels in North America, vol i., p. 143.

the juniper trees (*Cupressus thyoides*) as standing firmly in the softest places, supported by their long tap-roots. With other evergreens these trees form a shade, under which grows a multitude of ferns, reeds, and shrubs. The great cedar (*Cupressus disticha*) also flourishes under favourable conditions. Trunks of large and tall trees lie buried in the swamp. They are easily upset by extraordinary winds and covered in the mire, where, with the exception of the sap-wood, they are preserved. Much of this timber is found a foot or two from the surface, and is sawn into planks half under water. Bears inhabit the swamp, climbing the trees in search of acorns from the oaks, and gum berries. There are wild cats also, and occasionally a wolf is seen; so that there must often be conditions for the loss of these animals in the mire, and for the preservation of their bones. Indeed, in such a region as this, occupying an area of several hundred square miles, the amount and mixture of animal and vegetable matter, which may be collected in one great extended sheet, is not a little remarkable.

Rivers, in some regions, carry forward not only the small plants with the leaves and branches of the larger, but multitudes also of trees are thus sometimes transported, part of them retained within the sedimentary deposits of the rivers themselves, part swept out seawards. It is not among the long-cultivated lands that the amount of plants, great and small, carried downwards by rivers, is best observed, though during floods in them large trees are occasionally borne down their courses. It is in regions where man has not by his labours modified the growth of vegetation, or the course of rivers, that the transport of plants by running waters can be well studied. We then have conditions resembling those under which vegetable remains may in this way have been mingled with the sedimentary deposits of previous geological periods. On this account, the courses of rivers, such as those of the Mississippi and its tributaries, are still highly instructive, though in various ways other rivers, pursuing their courses through lands not yet cultivated in any part by man, may be still more so. The *snags* of the Mississippi, or great trees carried away from its banks, or those of its tributaries, and which are anchored, so to speak, by their roots upon the bottom of the stream, their heads bending with its strength, are well-known examples of the partial stoppage of trees on their course downwards. The same river, or rather one of its delta streams, named the Achafalaya, furnishes us with a good instance of a large accumulation of some of these drift trees within the last 80 years. About that time since numbers of these drift trees got

entangled in the channel, so that they no longer passed freely down it. Eventually they formed a mass, termed the Raft, distributed irregularly, and rising and falling with the waters, for a distance of twenty miles, closely matted together in some localities. In 1808 the cubic contents of this collection of drifted trees was estimated at 286,784,000 cubic feet.* If by any change of conditions the channel of the Achafalaya became little supplied with water, and the raft consequently fell in the channel and was covered over with fine sediment derived from muddy waters quietly working their way into the old river course, a long line of lignite, corresponding with twenty miles of the old channel of this river, might be the consequence.

When we regard the great rivers of the world, we can scarcely avoid considering that a large amount of plants and trees, differing in kinds and structure according to climates, must be annually entombed, in a manner to prevent that decay they would have suffered if left, after death, solely to atmospheric influences. No doubt much of this vegetation is still decomposed after transport by the rivers to their deltas, yet much also must be entombed in deposits excluding ordinary atmospheric influences, and leaving the plants under conditions favourable for their gradual alteration into lignite, or to the more advanced state of coal, should geological changes so permit. In deltas, also, we have, in the pools and lakes formed by the advance of the sediments thrust forward by the rivers, circumstances in many regions favourable to the growth of aquatic and swamp vegetation. In such situations, as they fill up by the occasional inflow of the muddy waters of the rivers in flood, and by the growth and partial decay of the vegetation, we have also conditions suited to the preservation of some of the plants, or their parts, often in the positions in which they grew, mingled with carbonaceous matter and beds of sediment. It may so happen, in rivers where sands as well as mud are forced forward, that by the occasional shifting of a stream, or the breaking away of a bank, previously barring the entrance of any portion of a main stream, sands may be thrust forward over accumulations of

* The 20 miles of length were estimated at 10 miles, this distance being considered as representing a close packing of the trees. The average breadth was taken at 220 yards, and the depth at 8 feet.—(Darby, Geographical Description of the State of Louisiana.) Rafts of this description, but of less size, are, as might be expected, found in other divisions of the Mississippi and its tributaries. Captain Hall (Travels in North America, vol. iii., p. 370) mentions being a witness of one of those falls of the banks of the Missouri, covered with trees, which throw so much drift wood into the Mississippi, the banks of the latter also contributing largely to the general mass.

this kind, their deposit marked by successive lateral and sloping additions, such as have been previously mentioned.

With regard to the preservation of animal remains on dry land, or in fresh water, we have to recollect that the rapacious animals very frequently devour the bones of the vertebrata which they destroy, and that the scavenger animals eat up those which the former may have left unconsumed, so that few bones generally remain exposed on dry land to be decomposed by atmospheric influences. It is very probable that in deserts, the bones of animals which have perished in them may be often buried beneath great sand-drifts, there to remain, perhaps, if decomposing causes be slight in such situations, until geological changes may again bring such deserts beneath waters, and consolidation or removal of the sands be effected, as the case might be. We have seen the bones of rabbits and birds exposed by a shift of some of our coast sand-hills, by which portions of old accumulations, marked by successive growths of vegetation, have been carried off by the winds.

Vertebrate animals are, in some countries, overwhelmed by the fall of parts of mountain sides or cliffs, so as to become buried deeply in situations where their bones are under conditions favourable for preservation. Occasionally, they are destroyed by the partial fall of sea cliffs on tidal coasts, while wandering beneath them when the tide may be out, their harder parts, perhaps, washed out to sea when the breakers may have subsequently removed the fallen mass. Such harder parts may thus become mingled with any sedimentary accumulations then forming, should they not be ground to pieces on the coast by the breakers.

While studying the mode in which the remains of vertebrate animals may be preserved without the aid of streams, pools, or lakes of fresh water, it will be observed that the clefts of rocks, in countries where such occur, are places into which more animals fall than might at first sight be thought probable. In some of our limestone districts, where caverns are found open to the surface, many an animal is lost, notwithstanding the precautions usually taken, so that we are prepared to expect that, in uncultivated regions, animals chased by others, coming suddenly upon the brink of a fissure and unable to clear it at a bound, often get precipitated into it. How far their remains may be preserved will necessarily depend upon circumstances. While even inaccessible to scavenger quadrupeds, many of these fissures are open to scavenger birds who descend and devour the flesh, leaving the bones. Scavenger insects can readily also consume the softer parts. The ultimate

preservation of the bones from the decomposing effects of atmospheric influences would depend upon their exclusion from them. The accumulation of clayey matter in the fissures, washed in from the tops or sides during rains, mingled often with fallen portions of rocks, forming the sides of the fissure, will tend to this end. Still better, however, would be their entombment by calcareous stalagmites and stalagtites, where these were formed in the fissures of limestones. In the latter case, we might have an ossiferous limestone breccia rising to the surface irregularly, the width varying with the form of the walls of the original fissure.

Caves, inhabited for a length of time by the same kinds of animals, during which they brought in their prey, so that such parts of themselves or of this prey which may have remained unconsumed accumulated, also afford opportunities for the preservation of vertebrate animal remains, according to circumstances. If these remains, even teeth, continued long under the decomposing conditions likely to obtain in such situations, without some protection afforded by clay in some caves, by stalagmites in limestone caverns, or by numerous fallen fragments, few traces would be expected, while, if these protecting influences existed, such remains might often be preserved.

It is, however, to the aid of water we have to look for the entombment of vertebrate remains in the largest quantities, though, no doubt, the labours of Buckland and others have taught us how much may be preserved in fissures and caverns. We have already noticed the loss of animals in bogs and swamps. In some regions, the collective amount of those which perish in this manner must be considerable. We have reason to believe that many mammals perish in lakes, sometimes sinking into soft ground on their borders, at others while endeavouring to cross them. In the former case they may be preserved, as in bogs and common swamps, in a nearly vertical position, their bones occurring relatively to each other as in life. In the latter, their bones may often be scattered. After decomposition had sufficiently advanced, so that the dead body floated, it may be either drifted to a shallow or deep side of the lake, supposing, for illustration, that both existed. If to the latter, and decomposition had still further advanced, and probably also the scavenger animals, both of the air and water, had consumed no small portion of it, the body might descend into deep water, with the bones still, as a whole, in their relative positions, so that if detrital or chemical deposits were there taking place, they would be in the condition to be so preserved. If drifted and stranded on

a shallow part of a lake, the body would be liable to be attacked with facility by scavenger land quadrupeds, which might not have ventured into the water of the deep parts of the lake for this purpose. In many instances, as those who may have seen the dead bodies of animals under such circumstances are aware, the bones would be eventually much scattered, part of them pulled upon the dry land and decomposed, if not eaten, while another part may, under favourable circumstances, again enter the lake, and be there enveloped by deposits in the progress of formation.

Whether land animals floated or not after being drowned in lakes must often depend upon the consumption of their flesh while submerged. The various regions of the world furnish us with different creatures inhabiting such pieces of water. In many warm climates, the bodies would soon be attacked by reptiles, capable of easily destroying their softer parts. In some countries, the crocodilian family would speedily proceed to devour them, and not the less greedily that some decomposition had taken place. By their aid some animals might get dismembered in such a way that the bones became finally much scattered, and the parts of the same animal be somewhat spread among lacustrine deposits. The crocodilians themselves add not a little to the remains of terrestrial vertebrata entombed in lake accumulations, by seizing animals on the shores and dragging them into the water.*

With respect to the remains of aquatic reptiles and fish in lakes, the voracity of many of these creatures is commonly so great, and the system of mutual prey so incessantly kept up among them, that entire skeletons would have to be preserved under very favourable conditions. The deltas of the great rivers, especially those in tropical regions, will afford opportunities for the study of the manner in which the remains of aquatic reptiles may become embedded in detrital matter. We have seen the caiman of Jamaica, when pursued, so bury himself in the mud of the lagoons, in which he delights to live, that occasionally there must be some difficulty of withdrawal from it.

Floods in rivers, particularly those of large size, flowing amid great plains, where the sudden rise of water covers a large area in a short time, concealing the more shallow portions, would appear

* The caiman of the great West India Islands in this way frequently obtains dogs, and sometimes goats, incautiously approaching a place where he may be lurking, perhaps half depressed in mud, with the tip of his snout at the surface of the water. The caiman is considered by the negroes so fond of dogs' flesh, that when a bent mangrove tree, with a running noose, may be placed to catch one, a dog in a stout stockade, in the line traced out for the caiman, is thought one of the best baits.

the means by which many mammals are swept off their feeding-grounds, drowned, and their dead bodies buried amid the detritus borne down at the same time. At such times, also, bones of mammals which remain strewed about in the more exposed situations, not consumed or decomposed, get mingled with the mud, silt, or sands, carried forwards, and finally deposited. To delta accumulations, whether in lakes or seas, such floods must, in certain climates, often bring down terrestrial mammals, mingling their remains with those of many reptiles.

Though, from their powers of flight and consequent escape, we should not expect to find birds caught by floods so as to be carried away, drowned, and, under favourable circumstances, their harder parts entombed, yet, as we do occasionally, though rarely, find the body of a land bird borne down a stream in countries and at times of the year when we have no reason to suppose that it has been shot or otherwise destroyed by man, perhaps we may look to this cause as one, however occasional and rare, by which remains of birds may be preserved. It is in districts where great floods suddenly rise over very extensive flat lands, particularly at times when the young of many birds inhabiting and breeding upon them are unable to fly far or at all, that we anticipate the more frequent surprises of this kind. Land birds occasionally fall into lakes and perish. We have seen instances in which land birds chased by hawks have fallen into lakes. Accidents causing death also now and then happen to the waders frequenting the margins of lakes, as also to birds which live habitually on their waters, either supporting themselves by fishing in the shallow parts, like the swans, or by the aid also of diving, like the duck tribe. The preservation of their bones, once at the bottom, in lacustrine accumulations, would be the same as with other animal remains.

Under all circumstances, perhaps, to floods passing over extensive flats, raising to the surface of the water the bodies of birds which have perished by natural deaths, and which may be capable of floating, or sweeping forwards the bones of others, not yet consumed by scavenger animals, we may look for the chief causes of the transport by water and entombment of the remains of birds in the resulting deposits.*

* Neither should we forget, when considering the manner in which birds' bones may be preserved within the boundaries of land, that they may get entangled among travertines, and thus may be entombed in lines and patches corresponding with such calcareous deposits as they form in streams or pools, as under favourable circumstances in Italy.

In the great deserts of the world, birds, such as ostriches, perishing, their remains

During floods also conditions are very favourable to the sweeping off of numerous insects, even those having the power of flight being caught up in the waters before they could escape. Multitudes of these insects are no doubt consumed by fish, yet the remains of others may readily be so mingled up with the sediment of the flood waters where it can be deposited, as to remain permanently encased by mud, silt, or sand. Seeing the avidity with which, in general, insects cast by myriads, as they sometimes are, on the surface of lakes or pools of water, are devoured by fish, when we discover their remains embedded in calcareous matter, as they have been, we should expect circumstances ill-suited to the habits of insectivorous fish and aquatic reptiles. It may be that in waters in certain pools or lakes charged with large quantities of carbonate of lime in solution by means of the needful carbonic acid, the latter may be so abundant as to drive off the insectivorous fish, and insect-eating aquatic reptiles.

We find the remains of land molluscs mingled with soils in many localities in sufficient abundance to show how capable the shells of these animals are of preservation when circumstances will permit. Though light as regards the absolute weight of each shell, the specific gravity of land shells is considerable, more approaching that of arragonite than of common calcareous spar.* In soils, the shells are ill placed for resisting decomposition beyond a certain amount of time, the waters containing carbonic acid readily percolating to them, so that in such situations they are, if not lately embedded, usually brittle, and not unfrequently broken. Among blown sands land shells are often abundant, some land molluscs especially delighting in such habitats.

In volcanic countries, or those over which, from their proximity to such countries, volcanic ashes may be scattered, and sometimes abundantly, land shells, and, indeed, various other land animals, may be completely covered over with coatings sufficient not only

may be often covered over by great sand drifts, and remain so long beneath, even supposing some change of drift to expose them, as to be no longer available as food to the animals which would otherwise consume them. Some may remain permanently covered, until, as previously mentioned, by a change of geological conditions, these deserts may be again submerged, and their sands be either removed or consolidated into rocks.

* When experimenting some years since upon the specific gravity of shells, we found those of the following land molluscs to be :—

Helix Pomatia	2·82
Bulimus decollatus	2·85
——— undatus	2·85
Auricula bovina	2·84
Helix citrina	2·87

to kill them, but to aid in the preservation of their hard parts. The fall of large quantities of ashes and cinders, discharged in some volcanic eruption, would appear to cause a greater sudden entombment of terrestrial animals, with the probability of preserving their more solid parts entire, than can be obtained without the aid of water, even including the moving sands of deserts. Volcanic districts are, in temperate and tropical regions, often fertile, abounding in vegetable and animal life, so that in regions, such as Sumbawa and Java, for example, land animals, including an abundance of molluscs, may be readily buried beneath discharges of lapilli and ash, such as were vomited forth from the volcano of Tomboro, in Sumbawa, in April, 1815.*

* The eruptions commenced on the 5th April, and continued more or less until the 10th, when they became more violent. A Malay prahu was on the 11th, though distant from Sumbawa, enveloped in utter darkness from the ashes in the air. Upon landing afterwards on the island, the commander found the country covered to the depth of three feet by ashes and cinders; and difficulty was experienced in sailing through the cinders floating on the sea. At Macasar, 217 nautical miles from Tomboro, the volcanic discharges were heard to such an extent that, supposing there was an engagement with pirates near at hand, the East India Company's cruiser "Benares," was despatched with troops on board to look after them. The following account, by the commander of the "Benares," obtained by Sir Stamford Raffles, will show the amount of ashes and cinders vomited forth:—

Proceeding south to ascertain the cause of the explosions heard, at 8 o'clock on the morning of the 12th, "the face of the heavens to the southward and westward had assumed a dark aspect, and it was much darker than when the sun rose; as it came nearer it assumed a dusky-red appearance, and spread over every part of the heavens; by ten it was so dark that a ship could hardly be seen a mile distant; by eleven the whole of the heavens was obscured, except a small space towards the horizon to the eastward, the quarter from which the wind came. The ashes now began to fall in showers, and the appearance was altogether truly awful and alarming. By noon the light that remained in the eastern part of the horizon disappeared, and complete darkness covered the face of day. This continued so profound during the remainder of the day that I," continues the commander of the "Benares," "never saw anything to equal it in the darkest night; it was impossible to see the hand when held close to the eyes. The ashes fell without intermission throughout the night, and were so light and subtile that, notwithstanding the precaution of spreading awnings fore and aft as much as possible, they pervaded every part of the ship."

"At six o'clock the next morning it continued as dark as ever, but began to clear about half-past seven, and about eight o'clock objects could be faintly observed on deck. From this time it began to clear very fast. . . . . . The appearance of the ship when daylight returned was most singular; every part being covered with falling matter. It had the appearance of calcined pumice-stone, nearly the colour of wood ashes; it lay in heaps of a foot in depth on many parts of the deck, and several tons of it must have been thrown overboard; for though an impalpable powder or dust when it fell, it was, when compressed, of considerable weight. A pint measure of it weighed twelve ounces and three-quarters; it was perfectly tasteless, and did not affect the eyes with a painful sensation; had a faint smell, but nothing like sulphur; when mixed with water it formed a tenacious mud difficult to be washed off."

Approaching Sumbawa on the 18th, the "Benares" encountered an immense quantity of pumice, mixed with numerous trees and logs with a burnt and shivered appearance. The fall of ashes at Bima, 40 miles from the volcano, was so great as to break in the Resident's house in many places. The Rajah of Saugar described some of the stones which fell there to have been as large as two fists, though not generally

The great eruption of Vesuvius in 79 furnishes us with an excellent example of the manner in which the surface of a country may be covered up by the discharge of volcanic ashes and lapilli, so that various works of art and use are preserved for our instruction. Pompeii not only shows us paintings still remaining on the walls of the houses, but also a great variety of delicate articles, extending to those of the women's dressing-cases. At Herculaneum we have even the writings of the time on papyri, in part still legible. We see an abundance of men's works as they were overwhelmed by the discharge of the ashes and cinders upon them, and often in a condition, after being thus buried beneath mineral matter, permeable to water, for 1800 years, which might not at first be expected. So little general injury seems to have been sustained by the town, even by the shocks of explosions so near, or earthquake movements, that the crushing in of house-tops by means of the weight of ashes and cinders, and the filling up of all corners by the finer dust, appear to have been the chief effects produced. Walking in the street of tombs at Pompeii it seems to require little else than the presence of persons clothed in the costume of the place when overwhelmed by cinders and ashes, to have that street presented to us as it appeared 1800 years since. As showing that not only bones may be preserved under such conditions, but the form of the flesh itself which clothed them, two remarkable instances have occurred at Pompeii, where parts of the human form retained their external shape, the enveloping ash having been sufficiently consolidated, before the decomposition of the fleshy parts. The thickness of the ashes and lapilli which covered up Stabiæ, Pompeii, and Herculaneum in 79, has been estimated as varying from 60 to 112 feet in depth.*

There are few things we can consider more suddenly destructive of terrestrial animal and vegetable life than these great volcanic eruptions, particularly within areas where several feet of lapilli and ashes can be accumulated over a considerable area within a few days. The whole surface previously clothed with vegetation,

above the size of walnuts. A great whirlwind is mentioned by the Rajah, "which blew down nearly every house in the village of Saugar, carrying the tops and light parts along with it. In the part of Saugar adjoining Tomboro, its effects were much more violent, tearing up by the roots the largest trees, and carrying them into the air, together with men, houses, cattle, and whatever else came within its influence." Many thousands of lives were lost, and the vegetation of the north and west sides of the peninsula was completely destroyed, with the exception of a high point of land where the village of Tomboro previously stood, and where a few trees still remained.—*Life of Sir Stamford Raffles.*

* Daubeny, "Description of Active and Extinct Volcanoes," 2nd edit., 1848, p. 221.

with a multitude of land molluscs and insects, with many birds and mammals, may be all covered with a thick coating of these volcanic products; many of the molluscs and insects close to the plants on which they may have been feeding. In regions where bogs prevail, large tracts of these vegetable accumulations may be buried, with any birds, insects, or molluscs frequenting them, by a thick layer of ashes and lapilli, the subsequent consolidation of which, by geological causes, might produce the deceptive appearance of a molten rock having flowed over them without producing those effects which would, under the latter supposition, have been anticipated. Indeed, when we have to study the fossil vegetation of some regions, a reference to the conditions under which trees and even bogs may be covered by volcanic ashes is one by no means to be neglected.*

In tideless seas, terrestrial animal and vegetable substances, borne down floating on the rivers, necessarily pass out over the dense waters of the sea to various distances, according to circumstances, and may be transported still further than the force of the river waters have carried them by favouring currents, should there be such, or by winds, the latter capable of driving them about in various directions, should they change. The body of a drowned animal, the decomposition of which is sufficiently advanced to give it the specific gravity capable of floating (and it should be recollected that it would float easier in sea than in fresh water, as regards its own specific gravity), may be thus drifted a considerable distance until eaten, or too much decomposed to float. Small animals may be readily consumed, bones as well as flesh, by the larger voracious fish; but the bones of the larger mammals might, under favouring circumstances, find their way to the bottom, even in deep tideless seas, like parts of the Mediterranean, to be there mingled with the remains of molluscs or other creatures inhabiting the same depths.

The observer has, in like manner, to consider the various land plants and trees which can be carried long distances, sometimes with live creatures still upon them, parts of the latter subsequently, at least those which may escape the voracity of marine animals,

* It is stated that in consequence of the great eruption of Skaptar-jökul in 1783, the atmosphere over Iceland was impregnated with dust for a long time. Traces of this dust were observed in Holland. It is evident that bogs in Iceland may readily become buried beneath volcanic ashes and cinders under such conditions. We may take the great explosion of the Souffrière, in Guadaloupe, in 1812, as an example of the destruction of vegetable and animal life, and of a considerable covering of both in many places in a tropical region. It was during this eruption that ashes were conveyed to Barbadoes by an upper current of wind, opposite to the trade wind.

scattered over various depths of the sea bottom. It will require little attention to see how often the dead shells of land molluscs get thrust out seawards, their modes of floatation at first being such as to keep them above water. The positions necessary for this purpose will depend upon the state of the sea surface at the time. If, notwithstanding the state of weather which may have caused floods in the interior of adjoining lands, lifting off the dead shells from the low grounds in multitudes, the sea be moderately calm, the land shells will be carried on with the river waters, but if there be a breaking sea they soon get upset and sink.

In such situations we have also to regard the mingling of detrital with organic matter, which may be effected by the pushing forward of the sands and gravel on the bottom of the rivers. Many a drowned animal may thus become mixed up with a delta advance, and many a river and land mollusc be included amid a general subaqueous drift. Trees often get entangled and buried on the coast, as well as floated off seaward.

Thus in tideless seas we have the ready means of transporting terrestrial and fluviatile vegetable and animal remains to various distances seaward, some under favourable circumstances, capable of being embedded in marine deposits at various depths, while others are included amid the detrital accumulations formed by the action of the rivers, thrusting out silt, sand, and gravel from the shores, not forgetting any calcareous deposits which may sometimes be added.

In estuaries we obtain a state of things somewhat different. In them a check is afforded at each flood tide, to all borne floating out by rivers, so that when great freshets prevail in the rivers, all caught up by the floods in the interior and floated off low grounds, or borne to the main streams by tributaries, are arrested in their progress. The floating bodies of animals, trees, and smaller plants, are thus not permitted to escape directly seaward, but are lifted by the height of the tide over any low grounds bordering the estuary, these flats, at such times, being more than commonly covered with water. When the ebb tide lowers the waters, the various substances floated over the estuary lowlands not unfrequently remain upon them, more particularly if any wind prevailing at the time forces them on the edges of the flooded lands. There is often a curious mixture of terrestrial, fluviatile, estuary, and more marine animal and vegetable remains, scattered over the estuary flats after such floods, more particularly should it happen, as it sometimes does on the western parts of the British Islands, that a heavy gale, accompanied by much rain, occurs at a time of spring tides, so that the

high tides combined with an on-shore wind, rising the sea waters still higher, are met by strong freshets from the land. Under ordinary conditions, fringes of estuary fuci, mingled with land plants, estuary crustaceans and molluscs and land shells, with here and there the remains of some creature, more strictly marine, are familiar to all visiting estuaries.

Although amid the deltas of rivers delivering their waters into tideless seas, among the lagoons formed and the coasts adjoining, there may be variable mixtures of fresh and sea waters, affording proper places for the growth and increase of vegetables and animals fitted for living in brackish water, the conditions are different from those of an estuary. In the one case the waters are stationary, except so far as floods from the interior may force forward an extra amount of fresh water, or a prevailing on-shore wind may drive in a greater volume of sea water; while in the other, large tracts are sometimes bare at one time and covered by water at another, the amount of the saline mixture being variable also, depending on the state of the tide and the volume of fresh water falling for the time into the estuary. And here it is necessary to remark that the observer should not consider as an estuary one of those great indentations of a coast, commonly termed an "arm of the sea," and which is but the consequence of the sea level cutting a previously-formed inequality of the land surface, not unfrequently the prolongation of some valley. No doubt the one kind of coast may sometimes shade into the other, but as regards the kind of life inhabiting estuaries, we should consider brackish water as essential to the latter; at all events to such an extent that at low tide a river, the waters of which become fresh or brackish, should occupy the channel left.

Under the conditions of an estuary silting up in the manner previously noticed, it must necessarily happen that the molluscs and other creatures inhabiting different surfaces, or small depths beneath them, died, such harder parts of them as might be preserved remaining at levels corresponding with such surfaces, here and there mingled according to circumstances, with vegetable and animal remains, drifted as above mentioned. It will be well to examine the manner in which the different parts of an estuary surface may vary at the same time as to the animal life existing upon it, from the creatures inhabiting the little rills of water which only get checked at spring tides, otherwise meandering amid the higher estuary mud or clay-flats, to those in or upon the sands in the more exposed situations, covered by every tide.

The manner in which terrestrial animals may become caught in the softer places should also receive attention, especially where springs, readily finding their way beneath silt and sand, form quaking or quick sands which engulf them, their bones remaining after the flesh has been consumed by the scavenger animals. An observer should by no means neglect the foot-prints of terrestrial animals, nor indeed of any leaving marks or trails, such having lately, and very deservedly, become of geological importance. These foot-prints are often excellently well preserved upon the mud or clay flats, or gently-sloping grounds of estuaries. Very many estuaries around the British Islands afford abundant opportunities for the study of the mixed foot-prints of birds and mammals upon the mud or clay, more especially during the heats of summer, and at neap tides, when extensive surfaces, covered at spring tides, may be bare and exposed to the drying influence of the sun. We have often seen the foot-prints of common gulls, where these birds have been busy around some mollusc, crustacean, or fish drifted on shore, and sufficiently in a fresh state for their food, most beautifully impressed upon clay or mud, hard dried by the sun, the courses of the birds, sometimes single, at others in pairs or more numerous, well preserved. In the same way the tracts of other birds are common, crossed here and there by those of rabbits, hares, stoats, and weazles, and occasionally of dogs. In some localities, after an area of mud or clay, thus trod upon during the difference of time between the spring and the neap tides, has been well dried by the heats of the summer sun, with deep cracks formed from loss of moisture, pieces of the most instructive kind may with care be taken away, further dried and preserved, and even baked into a brick substance, if the composition of the clay be well suited to the purpose. Mingled with these marks we have often also the trails of molluscs, as also those of estuary crustaceans, striving to regain the water, after finding themselves left by the tide.

It might at first be supposed that the rise of the tides over this, for the time, somewhat hard surface, marked by the foot-prints and trails of different animals, would entirely obliterate all traces of them. How far this may be effected will, however, depend upon circumstances. If the rise of the tides from neaps to springs were accompanied by much ripple or waves from winds, it would be anticipated that the fine detritus constituting the mud or clay would, when remoistened, be readily caught up in mechanical suspension, so that all traces of foot-prints and trails would be removed. In all situations where such ripple or waves could be

felt this would be expected. All parts of estuaries are, however, rarely exposed to such influences at the same time: many a nook remains tranquil; and in those where the accumulation of detritus is in progress, and films or fine layers of mud succeed each other, if one becomes hardened before another is deposited, a line of separation more or less permanent is usually established between them. We are sometimes able to separate these layers from each other, after careful drying, so that foot-prints are seen upon many surfaces, beneath each other. We have been fortunate in this respect with some portion of sun-dried mud of the Severn estuary, and Sir Charles Lyell has pointed out the manner in which the foot-prints of the sandpiper (*Tringa minuta*) are not only preserved in the red mud of the Bay of Fundy (a locality so favourable from its tides, for the exposure of much ground at the neaps), but also repeated upon the different layers of accumulation.

In some estuaries, long necks of sands and sandhills so, in part, cross their mouths, that bays of still or comparatively still water, occasionally of considerable area, occur behind them, the main streams of tide flowing elsewhere. Let us assume, for illustration, that fig. 50 (p. 55) represents some estuary of this kind, and that, instead of a shingle beach, *d* is a tract of sandhills, perhaps extending several miles in length, then *e* would be the kind of bay noticed, left in comparative quiet, as regards the stream of tide, flowing chiefly on the opposite coast. Much would of course depend upon conditions as to the kind of deposits effected at *e*, but under the supposition that the set of the tides was such as not to cause a sweep of the stream round this bay, it would be favourable for the occasional deposit of the finer sediment or mud borne down the river, *f*, by floods. At the same time it would be exposed to the drift of sand from the sandhills, *d*. In such localities, we have seen the foot-prints of mammals and birds, hardened in the sun, well strewed over by the drift sand from the sandhills; and it should be observed, that the same winds which were powerful enough to disturb the sandhills and cause the drift, would be prevented by the shelter afforded behind the same hills from disturbing the bay waters near the shore, these waters being under the lee of the sandhills, so that even in the shore and shallow waters the sand may be drifted over the mud or clay, filling up the hollows of the foot-prints.

Should the general surface of the land be subsiding gradually, as regards the sea level, it will be obvious that great estuaries may present conditions highly favourable to the preservation of the foot-

prints of animals, the actual remains of which, amid the detrital accumulations, may be most rare. Many aquatic birds frequenting estuaries at particular times, often when driven to seek their food in such situations, from tempestuous weather in their more common sea haunts, may thus leave their foot-prints, the conditions for the preservation of whose bones in the estuary deposits themselves would be of the most rare kind, indeed not to be expected, except under the accident of some individual being killed when up the estuary. With the most truly estuary birds, those which build and commonly live on estuary shores, the case might be different. Upon the supposition of a gradual change in the level of the sea, the land descending, we might have sands abundantly thrust forward over clay with foot-prints and trails. A lowering of a mass of sandhills, partly barring the mouth of an estuary, would at once place much arenaceous matter within the transporting influence of the tidal waters, to be drifted over mud flats, formed previously behind them. In some regions the mass of sand, either accumulated as partial and sub-aërial bars, or more gathered together by the sides of estuary mouths, to be again thrown into tides, however eventually other sandhills and tracts might arise (conditions continuing favourable), would be considerable.

That the remains of cetaceans should be found amid estuary accumulations, as also those of numerous fish, some of them more known as purely marine than estuary, will not surprise those who may have seen the porpoises dashing up the estuaries of our coasts in chase of fish which they have driven before them, and their occasional entanglement in shoal waters, when left by a quick-falling tide. Other cetaceans also get sometimes stranded. It is more common to find the chased fish, especially the smaller fry, driven on shore. The birds, no doubt, then pick up the fish abundantly, so that only a minor portion may leave their hard remains for entombment, and doubtless, also, the cetaceans often escape in the pools where they may be caught upon the rise of the tide, but there are still many chances for the preservation of the harder parts of these animals amid estuary accumulations which should not be neglected.

CHAPTER IX.

ORGANIC REMAINS IN MARINE DEPOSITS.—MODIFICATION OF CONDITIONS ON COASTS OF AMERICA.—OF PACIFIC OCEAN.—OF THE INDIAN OCEAN.—OF COASTS OF AFRICA AND EUROPE.—OF ARCTIC SEA.—DISTRIBUTION OF MARINE LIFE.—MODIFICATIONS FROM TEMPERATURE AND PRESSURE.—FROM LIGHT AND SUPPLY OF AIR.—RESEARCHES OF PROF. E. FORBES IN THE ÆGEAN SEA.—ZONES OF DEPTH.—PROF. LÖVEN ON THE MOLLUSCS OF NORWAY.—ZONES OF DEPTH IN THE BRITISH SEAS.—ORGANIC REMAINS DEPOSITED IN THE DEEP OCEAN.—ON COASTS.

It is in connexion with the sea, looking at the evidence afforded us by the various fossiliferous rocks of different geological ages, that we should look for the preservation of the great mass of animal remains amid the detrital and chemical deposits of the time. We have seen that, by means of rivers and winds, various plants and animals, or their parts, may be borne into the sea, and that in estuaries we may have a mixture of terrestrial and marine remains, and of others suited especially to such situations. In respect to estuaries, some so gradually change into arms of the sea, to be seen on the large scale in the Gulf and River of St. Lawrence, and other situations, and equally well in numerous localities of far less area, in various parts of the world, as for instance, in the Bristol Channel and the Severn estuary, that no marked distinctions can be drawn between the one and the other.

Viewing the coasts of the world generally, we not only have to regard all the modifications for the existence of marine animal life, arising from the more or less exposed or sheltered situations of headlands, bays, and other forms of shore, but also the mingling of fresh waters with the sea under the various circumstances connected with the drainage of the land into the sea. Let us consider the modifications of condition for the existence and entombment of marine animal life from Cape Horn to Baffin's Bay. First, there is the difference of climate, producing modifications of no slight order, more especially in moderate depths. From Cape Horn to the

West India Islands, with the exception of the Straits of Magellan, there is an unbroken oceanic coast, subject to the action of the tides, upon which bodies of fresh water are thrown by drainage channels in different places, the chief of which are the Rio de la Plata, the Rio de San Francisco, the Tocantins, the Amazons, and the Orinoco rivers, delivering the portion of rains and melted snows not taken up by the animal and vegetable life, or required for the adjustment of springs or other interior conditions of a large part of South America. After a line of coast little broken by rivers, we find extensive estuary conditions at the mouth of the Plata, and not far beyond Lake Mirim, about 100 miles long, a body of water apparently cut off from the ocean by coast action, and draining into another lake or lagoon, Lago de los Patos, having a channel still open to the main sea, and about 150 miles long, with an extreme breadth of about 50 miles. In these two bodies of water, receiving the drainage of the adjoining land, there are necessarily modifications of the ocean conditions for life, and for the entombment of its remains outside in the main sea. A range of coast succeeds, to which comparatively small rivers discharge themselves, until the San Francisco presents itself, and so on afterwards until the mouths of the Para and Amazons join in forming (including between them the Island of Marajo) great estuary conditions, the tides being felt up the latter river, it is stated, 600 miles, so that there are several in the river at the same time.

The mouths of the Orinoco present us with delta-form accumulations, and then comes the Carribbean Sea influenced by the ponded-back waters of the Gulf of Mexico, so that a kind of tideless sea shades into one where the tides are more felt. More northerly the Gulf stream is seen, transporting warmer waters to colder regions, and skirted by a shore, marked by a line of lagoons for above 200 miles on the coast of Florida, one of them named the Indian river, about 110 miles in length, with an extreme breadth of 6 miles; another, the Mosquito lagoon, being about 60 miles long, with the like extreme breadth. Thence a much-indented shore, on the minor scale, continues until we come to Cape Fear (Carolina), where the lagoon conditions obtain, a kind of barrier, broken by passages termed *inlets*, permitting the ingress and egress of sea waters. In Core, Pamlico, Albemarle, and Currituck Sounds, we find a great body of water of an irregular shape, measuring along the line of barrier separating them, except where broken by inlets from the ocean, about 160 miles in length. Rivers drain into this body of water in various directions, so that estuary conditions obtain

in different places, while the great barrier banks, a point of one of which forms Cape Hatteras, place it under a modification of the conditions outside in the main sea. More northward, we obtain the great indentation of Chesapeak Bay, with its minor breaks into the land, the chief of which is the Potomac; and then the Delaware Bay, with its river extending inland, the lagoon coast and its inlets continuing from Cape Charles (north entrance of Chesapeak Bay) towards the Delaware, and from near Cape Mary (Delaware Bay), about 85 miles to the northward. Next follows the mouth of the Hudson, and the modifications arising from the shelter of Long Island up the sound at its back, the lagoon character still apparent on part of its ocean coast. After shores variously indented, we reach the Bay of Fundy with all the modifications due to the great rise of tide (p. 78) at its northern extremities. This is succeeded by the great estuary conditions of the St. Lawrence, and finally the large indentions of Baffin's Bay and Strait and Hudson's Bay and Strait, and all the other channels of the cold regions of North America communicating with the Atlantic Ocean.

It is impossible, when directing our attention to this long line of coast, so variously modified in character, and necessarily so different in climate, not to see how very modified must also be the conditions for the existence of life and the preservation of any of its harder parts. One contemporaneous coating of sedimentary or chemically deposited matter must include the remains of very different creatures, either living upon or in the surface accumulations, as well as the vegetable and animal remains drifted into it from the land. The molluscs inhabiting the coasts of the cold regions would be expected to differ materially from those in the tropics, and the plants and terrestrial animals and amphibious creatures of the latter would vary from those in the former. The organic remains buried in the deposits of the Gulf of Mexico, though entombed at the same time as those in Baffin's Bay, could scarcely be expected to offer the same characters.

If, instead of the eastern coast of America, we look to the western, the first marked difference which presents itself is the absence of great rivers up the whole of the southern Continent and the land connecting it with the wide-spread northern part. Numerous sheltered situations are to be found amid the islands and inlets extending from Cape Horn to, and including the island of, Chiloe; after which, for about 6000 miles of coast, to the Gulf of California, the shores are little broken by indentations, except at Guayaquil and Panama, and do not present a single estuary of importance as on the eastern

side of the continent. The mixture of fresh water with the oceans on either side is very different, as are also the conditions for estuary life and the transport of terrestrial and fluviatile organic remains for entombment in the coast sedimentary accumulations. Even after we have passed the Gulf of California, and the Colorado delivering its waters at its head, there is, for about 2000 miles, from Cape S. Lucas to Vancouver's Island, a slightly-indented coast and a minor discharge of drainage waters, with the exception of those delivered by the Columbia or Oregon. Subsequently more northward, for about 800 miles, islands and inlets are common, offering modifications for the existence of marine life, as regards shelter and exposure to waves produced by winds, to Sitka Island and Cross Sound. After which comes the variously-indented coast extending to the Aleutian Islands, and so on to Behring Straits.

Though we have the same range through climates, the character of the two coasts of the American continent varies so materially that we can scarcely but expect very important modifications, as well in the life as in the physical conditions under which it is placed. We have not only to regard the very great difference in the amount of fresh waters discharged on the east and on the west, with its consequences, but also the ponded waters of the Mexican Gulf and their continuation into the Carribbean Sea, with the result, the Gulf Stream, on the one side and not on the other, not neglecting the important difference presented by the great Mediterranean Sea, of Hudson's Bay and Baffin's Bay on the east, and the kind of coast found on the west. To this also should be added the great barrier offered by America to the passage of tropical marine animals from one ocean to the other.*

It may be useful to glance at the great modification of conditions on the western side of the Pacific. Though a great portion of the drainage of Asia is disposed of in other directions, the surplus waters of a large area still find their way to the east coast. The

* According to M. Alcide d'Orbigny, of 362 species of molluscs in the Atlantic and Great Oceans, there is only one common to both, *Siphonaria Lessoni.* Of these 362 species, omitting the last, 156 belong to the Atlantic, and 205 to the Great Ocean. He also remarks that, if the two sides of the American continent be compared, the proportion, in the Atlantic, of gasteropod to lamellibranchiate molluscs, is 85 to 71, while in the Pacific it is 129 to 76. Of 95 genera considered to be proper to the shores of South America, 45 only are common to the two seas. This M. D'Orbigny attributes to the steep slopes of the west side, the Cordilleras rising near the coast, and rocks being more numerous than sandy shores, so that gasteropods would be expected to be more common, while the Atlantic coasts present mud, silt, and sand in great abundance, with gently-sloping shores for a large proportion of their length.—*Récherches sur les lois qui Président à la Distribution des Mollusques Côtiers Marins. Comptes Rendues*, vol. xix. (Nov. 1844). *Ann. des Sciences Naturelles*, Third Series, vol. iii., p. 193 (1845).

Saghalian river throws its waters, derived from a considerable area, behind the island of the same name, to be driven into the Okhotsk Sea on the north, or the Japan Sea on the south, as the case may be. Both these seas are, to a certain extent, separated from the main ocean by the range of islands, composed of the Kourile and Japanese islands, extending from Kamschatka to Corea, the Japan Sea especially, from the great mass of island land interposing between it and the Pacific, offering the character of a Mediterranean Sea.

Proceeding southerly we arrive at the Yellow Sea, which receives the abundant drainage effected by the Hoang Ho and its tributaries, and more southerly still we find the body of fresh water discharged into the sea by the Yang-tse-kiang. Thence, to the south, until the Si-kiang with its tributaries presents itself in the Canton estuary, comparatively minor rivers flow into the ocean, the coast being much indented, smaller rivers and streams often discharging in the upper parts of the indentations.

The Island of Hainan, with the great promontory stretching to meet it from the main Chinese land, forms the Gulf of Tonquin, into which the San-koi and other rivers discharge their waters. The amount of fresh water poured into the sea on the eastern coast of Cochin China is subsequently of no great importance, and it is not until we arrive at the delta of the Maikiang or Camboja that the sea is much influenced by the influx of fresh waters, an influence again, however, to be repeated at the head of the Gulf of Siam, by the outpouring of the Meinam, a river remarkably parallel with the Maikiang for about 700 miles, the latter holding a singularly straight course, as a whole, to the N.N.E., for about 1750 miles.* The remaining portion of the Asiatic continent, formed by the Malayan promontory, throws no important body of fresh waters into the sea in the form of a main river.

From Kamschatka nearly to the equator we thus have a continental barrier, for the most part not wanting in the outflow of bodies of fresh water, sufficient to produce marked influences on parts of the coasts, and consequently upon the conditions under which animal life may exist along it, and the remains of terrestrial and fluviatile plants and animals be drifted outwards into any sedimentary or chemical deposits now forming adjoining it. Minor parts of the ocean are also, to a certain extent, separated off by islands, the range of the Philippines and Borneo, in addition to those mentioned, tending to portion off the ocean down to the

* Considering the inference to be correct, as it appears to be, that the Latchou is the upper part of the Maikiang.

equator, so that, as a whole, a marked modification of physical conditions is observable on the east and west coasts of the Pacific Ocean.

From the equator southward we have no longer a mass of unbroken land on the west to compare with the continuous continent of America on the east. A barrier to the free passage of tropical animal life, supposing other conditions equal, is not presented on the west. Although much land rises above the surface of the sea, the mass of Australia not so very materially of less area than that of Europe, and Borneo and New Guinea exposing no inconsiderable surfaces, there are channels of water amid them permitting tropical marine creatures to extend themselves under fitting circumstances. Though, with the exception of Australia, the various islands may not offer areas sufficient for the accumulation and discharge of fresh waters equal in one locality to some of the great rivers of the world, collectively they embody conditions for the outflow of much fresh water around many of them, so that estuary and brackish water conditions obtain, and consequently physical circumstances fitted for the modification of life. So far as the eastern coast of Australia is concerned, it presents about 2000 miles of shore not more broken or affording more fresh water than the opposite coast of South America. The western part of the Pacific differs from the eastern portion in the multitude of points and small areas through which the floor of the ocean reaches the atmosphere, productive of a combination of influences affecting animal life and the accumulation of its harder remains.

While on this subject, it may be well to call attention to the material changes which would be effected if, by any of those alterations of the level of sea and land which the study of geology teaches may be reckoned by differences very far exceeding the depths required, channels of communication were established between the Atlantic and Pacific Oceans by a sufficient subsidence of the Isthmus of Panama, or the communication cut off between the Pacific and Indian oceans by an uprise of the land and sea bottom between Australia and the Malayan Peninsula, one stretching through Timor, Floris, Java, and Sumatra. If the multitude of oceanic-islands in the Western Pacific did not too much break up currents, we may suppose a certain amount of ponding up of waters inside the Moluccas, Borneo, and the Philippine Islands somewhat resembling that now effected behind the West India Islands, with perhaps also a modification of the Gulf Stream, escaping along the coast of China. Startling as, at first sight, such changes may appear,

the geological student has to accustom himself to consider modifications in the distribution of land and water, and elevations and depressions of a far more extended kind when he comes to reason upon facts connected with the accumulation and distribution of mineral and organic matter constituting rocks, formed at various geological periods.

In the Indian Ocean we have shores confined to the tropical and temperate regions. For nearly 2000 miles the coast of Australia, from Cape Leeuwin to Cape Bougainville, presents us with no known great river pouring out a volume of water sufficient to influence an extended area. The same with the island range of Timor, Floris, Java, and Sumatra, and up the Malay Peninsula, to the head of the Gulf of Martaban, where the Irawaddy thrusts out its delta and discharges a volume of fresh water, the drainage of a large area. From thence to the mouths of the Ganges no important amount of fresh water is carried out into the sea. The great volume thrown into the sea by this river has been already mentioned (p. 85). Hence to Cape Comorin we find rivers of varied magnitude, the most important of which are, proceeding southwards, the Mahanuddy, Godavery, Kistna, and Coleroon, draining, with minor streams, the great area of Southern India. As a whole, the Bengal Sea and Martaban Gulf receive a considerable quantity of fresh water, the discharge of which conveys a mass of detritus into the sea, and produces conditions in the waters and the sea bottom, which, beyond Cape Comorin, are not found for about 1000 miles, until we reach the Gulf of Cambay, into which the Nerbudda and other rivers discharge themselves. We find another volume of fresh water thrown into the sea by the Indus, still more northerly, after which we obtain the moderate outflow of fresh water of the coast of Beloochistan, the great indentation of the Gulf of Oman, and its continuation the Persian Gulf, the nearly-dry coast of Arabia, to the Arabian Gulf and its long-continued indentation, the Red Sea. From Cape Guardafui to the Cape of Good Hope, for about 4400 miles, the sea seems little influenced by any considerable discharge of fresh water on the coast, excepting in such places as at the mouths of the Zambesi and two or three other localities.

Looking at the Indian Ocean as a whole, any influences upon marine animal life from fresh waters poured into the sea, with the greater amount of terrestrial and fluviatile plants and animals drifted into the ocean by rivers, would be chiefly found in the Bengal Sea (including the Martaban Gulf) and upon the north-east

shores of the Arabian Sea, with one or two places on the east coast of Africa. Excepting Madagascar and Ceylon, the area occupied by islands is inconsiderable. The coasts bounding it on the east are those chiefly of considerable islands (the mass of Australia better deserving the name of a continent), so that in the tropical regions there is a free communication by means of sea channels with the Pacific. On the west, Africa bars all direct communication with the Atlantic, though at the same time the region terminated by the Cape of Good Hope and Cape Agulhas, trends southward, so comparatively little southward of the tropics, and currents (p. 93) so set from the Indian Ocean, round Cape Agulhas and up the south-western coast of Africa, that there is no great land boundary between tropical marine life in the one ocean and the other.* The Indian Ocean is now cut off from marine communication with northern regions (however this may have been effected in former geological times, even as late as the tertiary period, by means of waters uniting the Red and Mediterranean Seas), while it is well open to all marine life which may enter it, under fitting conditions, from the south. Herein it differs from the Atlantic and Pacific Oceans, which range from the Northern to the Southern Polar regions.

In the run of the African coast which bounds the Atlantic for so long a distance on the east, fresh waters flowing outwards through great drainage channels seem chiefly to occur at the Orange River, the Nourse, the Coanza, and the Congo, or Zaire, on the south of the equator, and at the Quorra, Gambia, and Senegal, on the north. The coast northward of the Senegal bounds for about 1000 miles the Atlantic on the one side, and the great African Desert on the other. From the Desert to Cape Spartel minor streams only fall into the sea. The great indentation of the Mediterranean then succeeds.

The European rivers discharged into the Atlantic, or the tidal seas and channels communicating with it, are inconsiderable streams as compared with the great rivers of the world; indeed a large portion of the European drainage finds its way into the Mediterranean, Black, Caspian, Baltic, and Arctic Seas. Such drainage as falls into the Caspian is evaporated in that sea, and that not so treated in the Black Sea is evaporated in the Mediterranean; with all which directly finds its way into the latter. So that from the

* Due regard has, however, to be paid to the temperature of the current, considered to be that of the mean of the ocean, which flows for some distance up the west coast of Africa, from the Cape of Good Hope, as also to that stated to run from the south end of Africa some way up the eastern coast.

Baltic alone the drainage waters of Europe find their way into the Atlantic, in addition to those which flow directly into it, or the tidal channels and seas communicating with it. Enough, however, escapes in this way, to give a varied character to the coast conditions, as regards the mingling of fresh with sea waters, under which aquatic life may be found and, in part, entombed, and the remains of terrestrial and fluviatile plants and animals be also accumulated.

In the Arctic Ocean, the coasts present us with much mingling of fresh water and sea, the drainage of a large portion of Asia and of a minor portion of Europe falling into it; part of the fresh water discharged into great indentations or arms of the sea, such as the White Sea and the Gulfs of Obi, Ieniseïsk, Khatangskii, and Kolima; part through deltas, as the Petchora and Lena; and part in a more ordinary form. The fresh water so supplied to the coasts of these regions is interrupted or lessened during many months of the year by the climate; much of it being arrested in the form of ice, to be let loose in the warmer months. The ice, also, in the seas of these high latitudes, necessarily modifies the coast conditions for life as it exists in the temperate and tropical shores of the world. The drainage delivered into the same ocean from North America is less important than from Europe and Asia. Of the North American rivers flowing into this ocean, the Mackenzie would appear the most important, succeeded by the Back and Slave Rivers. The land and sea are so mingled on the north coast of America, and the ice and snows so abundant, that the shore waters become much influenced thereby.

Looking to the Southern Ocean, we find the ice and snow of the Antarctic land most important, as regards the shore conditions. A great barrier of ice, indeed, there occupies the position of the coast for a great extent, so that both in the Arctic and Antarctic regions we have to regard ice accumulated round the land, or formed in the sea, as most materially influencing the existence of marine life and the preservation of its remains amid sedimentary and chemical deposits.

In such regions, also, we see the extension of marine life (vegetable and animal), and of air-breathing creatures (birds and mammals) feeding upon it beyond the range of terrestrial vegetation, and of animals directly consuming it or the creatures which first feed upon it.

Though such is the general fact, the conditions for the entombment of the remains of terrestrial animal and vegetable life in the

Arctic and Antarctic regions are, as respects the present distribution of land and sea, different. In the former, we have the delivery of important rivers into the sea, an abundance of water being discharged during the warm season when the ice is broken up at their mouths, and the interior ice and snows are melting. The Obi and its tributaries alone drain a large Asiatic area, extending from lat. 47° to 67°. The Jeniseï, rising from the Tangnou and Little Altai Mountains, likewise flows through 20° of latitude to 70° N., while the Lena and its tributaries, considered to drain 785,565 square (English) miles, rises (in lat. 57°) from the Jablonnoï or Stannovoï Mountains (the eastern portion of which looks upon the sea of Okhotsk), delivering itself into the Arctic Ocean, in about lat. 73° 38′ N. Other rivers, also, flow northerly for considerable distances from the south, such as the Dvina, Petchora, Khatanga, Anabara, Olia, Oleneck, Iana, and Kolima. In Northern America, also, the rivers, though not numerous, flowing northerly, still show a drainage extending to the south for several degrees of latitude, though much interrupted by lakes.* Thus the Mackenzie, delivering itself into the Arctic Ocean in about 69° N., flows from the Slave Lake by an outlet in about 61° N., giving 8 degrees of latitude for this course, during which the river receives the drainage from the Great Bear Lake. Regarding the Slave Lake as a mere interruption, by which the waters are spread over a wider space in a depression, the waters discharging themselves by the Mackenzie are derived from a drainage extending over a considerable area (estimated at about 510,000 square miles), and reaching down to lat. 52° 30′ N., by means of the Slave River (running out of the western end of Athabasca Lake), and the Athabasca (flowing into the same lake also at its western extremity).

In the northern parts of Europe and Asia, 3,000,000 square miles of which have been estimated as draining into the Arctic Ocean, and in some portion of North America, there are, therefore, conditions, particularly during the floods caused by the melting of the ice and snows, for thrusting forward the remains of terrestrial and fresh-water life into the northern seas, there to be mingled with detritus, upon the transport and accumulation of which ice has an important influence. We should expect that amid the intermixed land and sea, terrestrial animals often perish while crossing among the ice, at times when the latter is breaking up in the channels

* Collectively the lakes of North America constitute a marked feature in the physical geography of that part of the world. The volume of water in the chief lakes has been estimated at 11,300 cubic miles.

and gulfs, so that their bones are, under favourable conditions, preserved in any sedimentary matter accumulating beneath. No such conditions prevail in the southern continent, which navigators have lately made known to us. No great rivers there flow outwards, and neither terrestrial plants nor animals, directly or indirectly living upon them, furnish their remains for mixture with any sedimentary deposits which may be forming. All aid which great river drainages afford to the latter is cut off, and the little detritus that can be obtained from the land seems only capable of being so derived directly in the few localities exposed to the breakers during the short period of the year when the shores are not bounded entirely by ice. For the finer matter, not ice-borne, entombing the remains of life, we may probably look, as affording the chief supply, to ashes and lapilli vomited from volcanos, and scattered over adjacent seas.

Enough has been stated to show the unequal conditions as to climate and the mingling of fresh with sea waters along coasts. The observer has next to consider the varied character of the shores themselves as regards the shallowness or depth of the adjacent seas, and the modifications of temperature, pressure, access of light, and conditions of intermixed air thence arising. It has been above seen (p. 96), that the volume of ocean is so arranged as to the specific gravities of its waters, that an equal temperature, considered to be 39° 5′, reigns in the sufficiently deep parts from pole to pole, water of higher temperature rising above these more dense waters in tropical regions, and of a lower temperature towards the poles. Though this even temperature may prevail at the proper depths, it is necessarily modified as the seas become shallow, or currents may transport warmer or colder waters, as the case may be, from one oceanic area to another. As the coasts are approached in the parts of the world where warmer waters float above those of 39° 5′, we have conditions under which the temperature decreases downwards below the level of the sea to 7200 feet, and upwards in the air to the greatest heights of land. Viewing the subject generally, therefore, and as far as temperature is concerned, marine animals which could support a decrease of temperature equal to about 39° 5′ (the surface temperature being taken at 78°), could live from the level of the sea to the greatest depths in the equatorial ocean.* A higher temperature may be found under favourable conditions of shallow water and small tides in some

* It will be at once obvious that this difference of temperature is easily sustained by many land animals in different parts of the world.

tropical regions. In the polar areas, included within the belts of equal temperatures from the surface to the bottom of the sea, and within which colder waters, as a whole, float above those of 39° 5′, there is a different state of things. Still regarding the subject merely with respect to temperature, the animals capable of living in the tropical regions, and unable to support lower temperatures than 39° 5′, could not occupy the higher waters.

While in the equatorial parts of the world the temperature of the ocean may not be very materially altered on its surface, it is different with those portions of its higher waters exposed to the changes of winter and summer, so that the temperature of the surface waters is there more considerably modified, especially upon coasts. The animals living in the shallow waters of such regions are, therefore, liable to an amount of difference in temperature not experienced by those inhabiting the seas of the tropics. This is more particularly the case on the shores of tidal seas, with their estuaries, where, even at high water, large tracts of coasts may only be covered by shallow waters, becoming dry at low tide.

As regards mere temperature, it will be apparent that a vast volume of the southern ocean might be tenanted by similar life, extended over its floor at any depths from about 7200 feet at the equator, 3600 in lat. 45° S., the surface in 54° to 58° S., and 4500 feet in lat. 70° S.; and, probably, under the needful modifications, considering the different distribution of land and water on the south and on the north, in a similar manner towards the northern regions. Modifications, also, arising in the various seas communicating with the main ocean, and more or less separated from it, such as the Mediterranean, in the western part of which the waters beneath 200 fathoms have been supposed to remain at about a temperature of 55°,* must also be borne in mind.

With differences of depth, the observer has to consider the differences of pressure to which any animal or vegetable living in the sea would have to be subjected, so that such life would be very differently circumstanced, though under equal temperatures, at the depth of 7200 feet at the equator, and in the shallow waters of the

* M. Berard found, at a depth of 1200 fathoms (without reaching bottom), between the Balearic Islands, a temperature of 53°·4, the surface water being at 69°·8, and the air at 75°·2. From other observations in the western part of the Mediterranean, at the respective depths of 600 and 750 fathoms, and another not stated, it was found that the water was still at 55°·4, though the temperature of the surface water varied materially. M. D'Urville remarks that these experiments accord with some made by himself, also in the Mediterranean, at 300, 200, 250, 600, and 300 fathoms, when he obtained the respective temperatures of 54°·5, 54°·1, 57°·3, 54°·6, and 54°·8 —*Geological Manual*, 3rd edit., p. 25.

oceanic regions where that of 39° 5′ rises to the surface. We cannot suppose an animal so constructed as to sustain a pressure of more than 200 atmospheres at one time, and of 2 or 3 atmospheres at another. A creature inhabiting a depth of 100 feet would sustain a pressure, including that of the atmosphere, of about 60 pounds to the square inch, while one at 4000 feet, no very important depth, would have to support a pressure of about 1830 pounds to the square inch.

Animals, among other conditions for their existence, are adapted to a given pressure, or certain ranges of pressure, so adjusted that they can move freely in the medium, either gaseous or aqueous, in which they live. All their delicate vessels, and the powers of their muscles are adjusted to it. When the pressure becomes either too little or too great, the creature perishes; and, therefore, when acting freely in such a medium as the sea, an animal will not readily quit the depths in which it experiences ease. All are aware of the adjustment of an abundance of fish to the depths, to or from which they may frequently descend, by means of the apparatus of swimming bladders. This arrangement, however, only changes their specific gravities as a whole, the relative volume occupied by the air or gases in the swimming bladders, being the chief cause of difference, though, no doubt, also the squeezing process at great depths would diminish the volume of such other parts of their bodies, as were in any manner compressible, the reverse happening with a rise from deep waters to near the surface. So adjusted to given depths do these swimming bladders appear for each kind of fish, that it has been observed that the gas or air in the swimming bladders of fish brought up from a depth of about 3300 feet (under a pressure of about 100 atmospheres), increased so considerably in volume, as to force the swimming bladder, stomach, and other adjoining parts outside the throat in a balloon-formed mass.*

* Pouillet, Elémens de Physique Expérimentale, tom. i., p. 188. Seconde Edition.

As regards the pressure and different depths in the sea, Dr. Buckland mentions (Bridgewater Treatise, vol. i, p. 345) that "Captain Smyth, R.N., found, on two trials, that the cylindrical copper air-tube, under the vane attached to Massey's patent log, collapsed, and was crushed quite flat, under the pressure of about 300 fathoms (1800 feet). A claret bottle, filled with air, and well corked, was burst before it descended 400 fathoms (2400 feet). He also found that a bottle filled with fresh water, and corked, had the cork forced in at about 180 fathoms (1080 feet). In such cases the fluid sent down was replaced by salt water, and the cork which had been forced in was sometimes reversed." Dr. Buckland adds that Sir Francis Beaufort had informed him that he had frequently sunk corked bottles in the sea more than 600 feet deep, some of them empty, others containing some fluid. "The empty bottles were sometimes crushed, at others the cork was forced in, and the fluid exchanged for sea water. The cork was always returned to the neck of the bottle, sometimes, but not always, in an inverted position." Dr. Scoresby (Arctic Regions, vol. ii., p. 193) gives an account

While thus some kinds of marine animals have the power to adjust their specific gravities to the medium in which they may be placed, some molluscs, such as the nautilus, possessing it, others appear unable, under ordinary conditions, to raise themselves much above the sea bottom. It will be evident that the more their component parts are incompressible, and the fluids in them agree with the specific gravity of the sea in which they live (and the specific gravity of the sea does not appear to vary from any increase of saline matters in it to great depths, though water being slightly compressible, it will become more dense according to depth), the less they would experience the difficulties of a change of depth. On the contrary, the more any parts may be compressible, and air or gaseous matter be included in their bodies, the less would they suffer changes of depth with impunity.

That light should have its effect upon marine as upon terrestrial vegetation we should expect, the light of day being important as well to one as the other, viewing the subject as a whole. It would evidently, also, be important to all marine creatures possessing the organs of vision, so that we should anticipate that the great mass of fish, crustaceans and molluscs which possessed eyes, would occupy situations and levels in the sea where they could obtain the light needful to them. The *Pomatomus Telescopium*, caught at considerable depths in the Mediterranean (near Nice), is considered to afford an example of adjustment to the minor amount of light reaching its ordinary abode, its eyes being remarkable for their magnitude, and apparently constructed to take advantage of all the rays which can penetrate the depths at which it lives. While, however, light may be absolutely needed for the existence of some marine life, it is not obviously necessary to others, those not possessing eyes. Many marine creatures seem to flourish under conditions in which it can be of little value, at the same time the influence of light may often be of importance where it is not suspected.

It is not improbable that to the power of obtaining a proper amount of disseminated atmospheric air in waters, we may look for a very important element in the existence of animal and, indeed, of vegetable life in the sea. To the one and the other oxygen seems essential. At the junction of the sea and atmosphere, we have the best conditions for the absorption of the air by water, the agitation of the surface from the friction of the atmosphere on the sea, particularly during heavy gales of wind, being especially

---

of a boat pulled down to a considerable depth by a whale, after which the wood became too heavy to float, the sea water having forced itself into its pores.

favourable for a mechanical mixture of the two, assisting the absorption of the air.* Of the amount of air, or rather of the apparently needful element, oxygen, at various depths in the sea, we seem to possess no very definite information, so that researches on this head are very desirable. From observations by M. Biot, on the gaseous contents of the swimming-bladders of fish, it has been inferred that such contents probably vary according to the depths at which such fish live. He found these swimming bladders nearly filled with pure nitrogen when they were those of fish inhabiting shallow waters, and with oxygen and nitrogen, in the proportion of $\frac{9}{10}$ of the former to $\frac{1}{10}$ of the latter, when those of fish living at depths of from 3000 to 3500 feet.

According to M. Aimé, the amount of air disseminated in the waters of the Mediterranean, opposite Algiers, is nearly constant from the surface to the depth of 5250 feet.†

We might assume that, from its immediate contact with the air, surface waters would more readily obtain any needful dissemination of it than those situated at greater depths, so that the mode of consuming oxygen would be adjusted to such conditions, animal life inhabiting great depths being so formed as to require it at considerable intervals. In tidal seas we find certain molluscs adjusted to live in situations exposed to the atmosphere during the fall of every tide, while others inhabit places always covered by sea, except, perhaps, at equinoxial spring tides. From inhabiting shores some molluscs are commonly considered as littoral species, while others are well known as rarely obtained except in deep waters.

Although general views may have been some time entertained with respect to the modification of marine life, depending upon the temperature, pressure, light, and ability to procure oxygen under which it may be placed,‡ it could scarcely be said that we had sufficient data for the philosophical consideration of this subject until the labours of Professor Edward Forbes in the British and Ægean Seas supplied the necessary information.

Professor E. Forbes pointed out that with regard to primary

* The friction of air upon fresh-water lakes produces the same result, intermingling the air and water. Cascades and waterfalls intermix them in many rivers, those especially in which fish swimming high, or inhabiting minor depths, most flourish.

† Comptes Rendue de l'Académie des Sciences, 1843, vol. xvi., p. 747.

‡ The author entered somewhat at length on this subject, in 1834, in his Researches in Theoretical Geology, chapters xi., xii., and xiii. To this work a table was appended by Mr. Broderip, containing all the information then known respecting the depths and kind of bottom at which recent genera of marine and estuary shells had been observed.

influences, the climate of the Eastern Mediterranean was uniform, and that the absence of certain species in the Ægean Sea, characteristic of the Western Mediterranean, was rather due to a modification in the composition of the sea water, from the impouring of the less saline waters of the Black Sea, than to climate.* The influx of river water produces its consequences; and it is remarked that, among 46 species of testacea collected on the shore at Alexandria, there were 4 land and fresh-water molluscs, 3 of which are of truly subtropical forms,† so that while in one part of the Mediterranean forms of this character are mingled with the ordinary marine testacea, in another, as at Smyrna or Toulon, the *Melanopsis* is mixed with them near the former, and characteristic European pulmonifera near the latter. It is also shown by Professor E. Forbes, that while vegetables of a subtropical character may be borne down by the Nile, into the Mediterranean on the one side, accompanying the remains of crocodiles and ichneumons, the Danube may transport parts of the vegetation of the Austrian Alps, with the relics of marmots and mountain salamanders, the marine remains mingled with these contemporaneous deposits retaining a common character.

With respect to modifications in conditions arising from depth, Professor E. Forbes divides the Eastern Mediterranean into eight regions, each considered to be characterised by its fauna, and also by its plants, where they exist. Certain species were found confined to one region, and several were ascertained not to range into the next above, whilst they extended into that beneath. "Certain species," he adds, "have their maximum of development in each zone, being most prolific of individuals in that zone in which is their maximum, and of which they may be regarded as especially characteristic. Mingled with the true natives of every zone are stragglers, owing their presence to the action of the secondary influences which modify distribution. Every zone has also a more or less general mineral character, the sea bottom not being equally variable in each, and becoming more and more uniform as we descend. The deeper zones are greatest in extent; so that whilst the

* He attributes to this cause the dwarfish character of the molluscs, with few exceptions, when compared with their analogues in the Western Mediterranean. "This is seen most remarkably in some of the more abundant species, such as *Pecten opercularis*, *Venerupis irus*, *Venus fasciata*, *Cardita trapezia*, *Modiola barbata*, and the various kinds of *Bulla*, *Rissoa*, *Fusus*, and *Pleurotoma*, all of which seemed as if they were but miniature representations of their more western brethren. To the same cause may probably be attributed the paucity of *Medusæ*, and of corals and corallines. Sponges only seem to gain by it."—Report of the British Association, vol. xii., p. 152, (Meeting of 1843).

† *Ampullaria ovata*, *Paludina unicolor*, and *Cyrena orientalis*.

first, or most superficial, is but 12, the eighth, or lowest, is above 700 feet in perpendicular range."*

While tracing the first region or littoral zone, which is thus limited to 12 feet, all the modifications arising from kind of bottom, rock, sand, or mud, are shown to have their influences, and the effects of wave action, bringing up the exuviæ of animals inhabiting the next region beneath, are pointed out. The second region is estimated at 48 feet, ranging from 2 to 10 fathoms; the third at 60 feet, between the levels of 10 to 20 fathoms; the fourth at 90 feet (20 to 35 fathoms); the fifth at 120 feet (35 to 55 fathoms); the sixth at 144 feet (55 to 79 fathoms); the seventh at 150 feet (80 to 105 fathoms); and the eighth, all explored below 105 fathoms, amounting to 750 feet, more than twice the depth of all the other regions taken together, the total depth amounting to 1380 feet.

So complete are the modifications in invertebrate life, produced by the conditions in these various zones or regions, that only two species of molluscs were found common to the whole eight—viz., *Arca lactea* and *Cerithium lima*, "the former a true native from first to last, the latter probably only a straggler in the lowest." Three species were found common to seven regions;† nine to six regions:‡ and seventeen to five regions.§ With regard to geographic distribution and vertical range in depth, Professor E. Forbes remarks that those species which possess the one exhibit the other, more than one-half of those having an extensive range in depth, extending to distant localities, in nearly every case to the British seas, some still further north, and some in the Atlantic, far south of the Straits of Gibraltar. He concludes "that the extent

* British Association Reports, vol. xii., p. 154.

† *Nucula margaritacea*, *Marginella clandestina*, and *Dentalium 9-costatum*; the second considered to have possibly dropped into the lower zones from floating sea-weeds.

‡ *Corbula nucleus.*
Neæra cuspidata.
Pandora obtusa.
Venus apicalis.
Turritella 3-plicata.
Triforis adversum.
Columbella linnæi.
Cardita trapezia.
Modiola barbata.

§ *Neæra costellata.*
Tellina pulchella.
Venus ovata.
Cardita squamosa.
Arca tetragona.
Pecten polymorpha.
—— *hyalinus.*
—— *varius.*
Crania ringens.
Natica pulchella.
Rissoa ventricosa.
—— *cimicoides.*
—— *reticulata.*
Trochus exiguus.
Columbella rustica.
Conus mediterraneus.
Terebratula detruncata.

of the range of a species in depth is correspondent with its geographical distribution."*

As regards the influence of light, Professor E. Forbes presents us with facts connected with the molluscs and other animals, deserving much attention and extended research, due allowances being made for the modifications produced, as he points out, and to be attributed in many cases to an abundance of nullipores, and to a beautiful pea-green sea-weed, *Caulerpa prolifera*. The majority of shells in the lower zone were found to be white, or, when tinted, of a rose colour, few exhibiting any other hues. In the higher zones, the shells, in a great many instances, exhibited bright combinations of colour. The animals also of the testacea and radiata, in the higher zones, were much more brilliantly coloured than in the lower, where they are usually white, whatever the colour of the shell may be.†

The researches of Professor E. Forbes have led him not only to attach great value to the bottom in or on which marine animals may live (and it will be obvious that creatures whose habits may be suited to mud would find themselves ill at ease upon rocky ground alone), but also to point out the effects produced by the accumulation of the harder parts of successive generations of marine animals

* Reports of British Association, vol. xii., p. 171.

"If," observes the Professor, "we inquire into the species of Mollusca which are common to four out of the eight Ægean regions in depth, we find that there are 38 such, 21 of which are either British or Biscayan, and 2 are doubtfully British; whilst of the remaining 15, 6 are distinctly represented by corresponding species in the north. Thus among the Testacea having the widest range in depth, one-third are Celtic or northern forms: whilst out of the remainder of Ægean Testacea, those ranging through less than four regions, only a little above a fifth are common to the British seas. One half of the Celtic forms in the Ægean, which are not common to four or more zones in depth, are among the cosmopolitan Testacea, inhabiting the uppermost part of the littoral zone."

† Professor E. Forbes adds, "In the seventh region, white species (of Testacea) are also very abundant, though by no means forming a proportion so great as in the eighth. Brownish-red, the prevalent hue of the Brachiopoda, also gives a character of colour to the fauna of this zone; the crustacea found in it are red. In the sixth zone, the colours become brighter, reds and yellows prevailing, generally, however, uniformly colouring the shell. In the fifth region, many species are banded or clouded with various combinations of colours, and the number of white species has greatly diminished. In the fourth, purple hues are frequent, and contrasts of colour common. In the second and third, green and blue tints are met with, sometimes very vivid, but the gayest combinations of colour are seen in the littoral zone, as well as the most brilliant whites."

Respecting the colour of the animals of Testacea, the genus *Trochus* is selected as "an example of a group of forms mostly presenting the most brilliant hues both of shell and animal; but whilst the animals of such species as inhabit the littoral zone are gaily chequered with many vivid hues, those of the greater depth, though their shells are almost as brightly coloured as the covering of their allies nearer the surface, have their animals for the most part of an uniform yellow or reddish hue or else entirely white." Reports Brit. Assoc., vol. xii, p. 173.

upon the same bottom, thus, in fact, altering its condition, so that they may die out from this increase.* He considers that until the old conditions be restored by a new accumulation of detrital matter different from that presented by the animal exuviæ, the same animals would not find the kind of bottom suited to them; and the geological bearing of this view is shown to be illustrated by the bands or layers of fossils so frequently found interstratified with common sedimentary matter.† In conclusion, Professor E. Forbes adverts to the evidences of the existing fauna of the Ægean which would be presented if its bottom were elevated into dry land, or the sea filled up by sedimentary deposits. While the remains of some animals would afford the needful evidence of their existence, and occur under circumstances whence the probable depths at which they lived might be inferred: of other anmals, very abundant in the present seas, no trace would be found.‡

While Professor E. Forbes was thus investigating the conditions under which marine life existed in the Eastern Mediterranean, it fortunately so happened that Professor Löven was engaged in researches leading to general and similar conclusions respecting the modifications in marine life on the coast of Norway. Though both localities are so far similar that the shores are for the most part rocky, and deep water to be often obtained near the coast, they differ as to climate, and as to the sea being tideless in the Eastern

* He illustrates this point by beds of scallops (*Pecten opercularis*), or of oysters, which, when considerably increased, give rise to a change of ground, by the accumulation of their shells, so that the race dies out, and the shelly bottom becomes covered over by sedimentary matter.—*Edinburgh New Phil. Journal*, vol. xxxvi., p. 324.

† In his paper on the light thrown on Geology by Submarine Researches, being the substance of a communication made to the Royal Institution of Great Britain, on the 23rd February, 1844 (Edinburgh New Phil. Journal, vol. xxxvi., p. 318, 1844), Professor E. Forbes, while remarking on all varieties of sea bottom not being equally capable of sustaining animal and vegetable life, observes, "In all the zones of depth, there are occasionally more or less desert tracks, usually of sand or mud. The few animals which frequent such tracks are mostly soft and unpreservable. In some muddy and sandy districts, however, worms are very numerous; and to such places many fishes resort for food. The scarcity of remains of testacea in sandstones, the tracks of worms on ripple-marked sandstones, which have evidently been deposited in a shallow sea, and the fish remains often found in such rocks, are explained in a great measure by these facts."

‡ The following are the inferences on this head, inferences extremely valuable respecting the animal life existing at different geological periods:—

"1. Of the higher animals, the marine Vertebrata, the remains would be scanty and widely scattered."

"2. Of the highest tribe of Mollusca, the Cepholopoda, which though poor in species is rich in individuals, there would be but few traces, saving of the Sepia, the shell of which would be found in the sandy strata forming parts of the coast lines of the elevated sea-bed."

"3. Of the Nudibranchous Mollusca there would not, in all probability, be a trace to assure us of their having been; and thus, though we have every reason to suppose

Mediterranean and oceanic off Norway. While adverting to the modifications of life at different depths, Professor Lóven attributes much of the character of the submarine life off the coasts of Norway

---

from analogy that those beautiful and highly-characteristic animals lived in the tertiary periods of the earth's history, if not in older ages, as well as now, there is not the slightest remain to tell of their former existence."

"4. Of the Pteropoda and Nucleobranchiata, the shell-less tribes would be equally lost with the Nudibranchiata, whilst of the shelled species we should find their remains in immense quantity, characteristic of the soft chalky deposits derived from the lowest of our regions of depth."

"5. The Brachiopoda we should find in deeply-buried beds of nullipore and gravel, and from their abundance we could at once predict the depth in which those beds were formed."

"6. The Lamellibranchiate mollusca we should find most abundant in the soft clays and muds, in such deposits generally presenting both valves in their natural positions, whilst such species as live on gravelly and open bottoms would be found mostly in the state of single valves."

"7. The testaceous Gasteropoda would be found in all formations, but more abundant *in gravelly than in muddy deposits. In any inferences* we might wish to draw regarding the northern or southern character of the fauna, or on the climate under which it existed, whether from univalves or bivalves, our conclusions would vary according to the depth in which the particular stratum examined was found, and on the class of mollusca which prevailed in the locality explored."

"8. The Chitons would be found only in the state of single valves, and probably but rarely, for such species as are abundant, living among disjointed masses of rock and rolled pebbles, which would afterwards go to form conglomerate, would in all probability be destroyed, as would also be the case with the greater number of sublittoral Mollusca."

"9. The *Mollusca tunicata* would disappear altogether, though now forming an important link between the Mediterranean and more northern seas."

"10. Of the Arachnodermatous Radiata, there would not be found a trace, unless the membranous skeleton of the *Velella* should, under some peculiarly favourable circumstances, be preserved in sand."

"11. Of the Echinodermata, certain species of *Echinus* would be found entire; species of *Cidaris*, on account of the depth at which that animal lives, would not be unfrequent in certain strata, as the region in which it is found bounds the great lowermost region of chalky mud; the spines would be found occasionally in that deposit, far removed from the bodies to which they belonged. Starfishes, saving such as live on mud or sand, would be only evidenced by the occasional preservation of their ossicula. Of the extent of their distribution and number of species no correct idea could be formed. Of the numerous *Holothuriadæ* and *Sipunculidæ*, it is to be feared there would be no traces. The single Crinoidal animal would be easily preserved entire, but its ossicula and cup-like base would be found in the more shelly deposits."

"12. Of the Zoophyta, the corneous species might leave impressions resembling those of Graptolites in the shales formed from the dark muds on which they live. The *Corals* would be few, but perhaps plentiful in the shelly beds, mostly, however, fragmentary. The *Cladocora cæspitosa*, where present, would infallibly mark the bounds of the sea, and, from the size of its masses, might be preserved in conglomerates where the testacea would have perished. The *Actiniæ* would have disappeared altogether."

"13. Of the sponges, traces might be found of the more silicious species when buried under favourable circumstances."

"14. The Articulata, except the shelled annelides, would be for the most part in a fragmentary state."

"15. Foraminifera would be found in all deposits, their minuteness being their protection; but they would occur most abundantly in the highest and lowest beds, distinct species being characteristic of each."

to variations in the sea-bottom, always, however, making allowances for the depth,* thus agreeing with the general views of Professor Forbes.

While marine life is thus found adjusted to different zones of depth on the ocean shores of Norway and the east part of the Mediterranean, always carefully considering the local and physical conditions, it becomes the more interesting to have direct evidence of the adjustments which may be effected on the great and gentle slopes bounding some coasts, such as those so important on the eastern coasts of America. Respecting these great detrital fringes off coasts, among which may be classed, though very small, comparatively, the shallow seas around the British Islands, the area of

---

"16. Tracts would be found almost entirely deficient in fossils, some, such as the mud of the Gulf of Smyrna, containing but few and scattered; whilst similar muds in other localities would abound in organic contents. On sandy deposits, formed at any considerable depth, they would be very scarce and often altogether absent. Fossiliferous strata would generally alternate with such as contain few or no organic remains. Whilst at present the littoral zone presents the greatest number and variety of animal and vegetable inhabitants, including those most characteristic of the Mediterranean Sea, when upheaved and consolidated, their remains would probably be imperfect as compared with those of the natives of deeper regions, in consequence of the vicissitudes to which they are exposed, and the rocky and conglomeratic strata in which the greater number would be embedded. A great part of the conglomerates and sandstones found would present no traces of animal life, which would be most abundant in the shales and calcareous consolidated muds."—Prof. E. Forbes' Reports, Brit. Association, vol. xii., p. 176.

* Professor Lóven observes, "As to the regions, the littoral and laminarian are very well defined everywhere, and their characteristic species do not spread very far out of them. The same is the case with the florideous Algæ, which is most developed nearer to the open sea But it is not so with the regions from 15 to 100 fathoms (90 to 600 feet). Here there is at the same time the greatest number of species, and the greatest variety of their local assemblages; and it appears to me, that their distribution is regulated, not only by depths, currents, &c., but by the nature of the bottom itself, the mixture of clay, mud, pebbles, &c. Thus, for instance, the many species of Amphidesma, Nucula, Natica, Eulima, Dentalium, &c., which are characteristic of a certain muddy ground at 15 to 20 fathoms, are found together at 80 to 100 fathoms. Hence it appears, that the species in this region have generally a wider vertical range than the littoral, laminarian, and perhaps as great as the deep-sea coral. The last-named region is with us characterised, in the south, by *Oculina ramea* and Terebratula, and in the north, by Astrophyton, Cidaris, *Spatangus purpureus* of an immense size, all living, besides Gorgoniæ and the gigantic *Alcyonium arboreum*, which continues as far down as any fisherman's line can be sunk. As to the point where animal life ceases, it must be somewhere; but with us it is unknown. As the vegetation ceases, at a line far above the deepest regions of animal life, of course the zoophagous mollusca are altogether predominant in these parts, while the phytophagous are more peculiar to the upper regions. The observation of Professor E. Forbes, that British species are found in the Mediterranean, but only at greater depths, corresponds exactly with what has occurred to me. In Bohuslan (between Gottenburg and Norway), we found, at 80 fathoms, species which, in Finmark (on the north), may be readily collected at 20, and on the last-named coast, some species even ascend into the littoral region, which, with us here on the south, keep within 10 to 11 fathoms."—*On the Bathymetrical distribution of submarine life on the northern shores of Scandinavia.*—British Association Reports, Notices, and Abstracts, vol. xiii., p. 50.

which inside depths, not exceeding 600 feet, will be seen by reference to fig. 65 (p. 91), we should anticipate disturbing conditions much affecting the distribution of some portion of the marine life upon them. With regard to a knowledge of the distribution of marine life in the British seas, we are indebted to the researches of Professor E. Forbes, commenced anterior to those undertaken in the Ægean Sea.* It was while prosecuting these researches that he ascertained the value in these investigations of the power of mollusca to migrate.† He has pointed out that they do so in their larva state, ceasing "to exist at a certain period of metamorphosis, if they do not meet with favourable conditions for their development, *i. e.*, if they do not reach the particular zone of depth in which they are adapted to live as perfect animals."‡

Professor E. Forbes divides the British seas into four zones of depth: 1, the Littoral; 2, the Laminarian; 3, the Coralline; and, 4, the Coral.§ The littoral zone lies between high and low water mark, varying in extent according to the rise and fall of tide, and the shallowness or depth of the shore. "Throughout Europe, wherever it consists of *rock*, it is characterized zoologically, by species of *Littorina*; botanically, by *Corallina*; where *sandy*, by the presence of certain species of *Cardium*, *Tellina*, and *Solen*; where *gravelly*, by *Mytilus*; where *muddy*, by *Lutraria* and *Pullastra*." The littoral is divisible into minor zones.‖ The Laminarian zone is the belt commencing at low-water mark, and extending to the depth of 7 to 15 fathoms (42 to 90 feet). Algæ are common, and numerous animals inhabit the forests composed of them. "Among

* The first notice of them was published in the Edinburgh Academic Annual for 1840.

† In 1840, he gave a summary of seven years' observations at a particular season of the year.—*Annals of Natural History*, vol. iv.

‡ Edinburgh New Phil. Journal, vol. xxxvi., p. 325, 1844. Speaking of the manner in which the larvæ and eggs may be transported, it is observed that "if they (the larvæ) reach the region and ground of which the perfect animal is a member, then they develop and flourish; but if the period of their development arrives before they have reached their destination, they perish, and their fragile shells sink into the depths of the sea. Millions and millions must thus perish, and every handful of the fine mud brought up from the eighth zone depth in the Mediterranean, is literally filled with hundreds of these curious exuviæ of the larvæ of mollusca."

§ These zones, originally pointed out in 1840, are considered to have been established by subsequent researches (Memoirs of the Geological Survey of Great Britain, vol. i., p. 371, 1846). Professor Forbes remarks that the two first regions had been previously noticed by Lamouroux, in his account of the vertical distribution of sea weeds; by Audouin and Milne Edwards in their observations on the natural history of the coast of France; and by Sars, in the preface to his Bagtivelser og Jagtivelser.

‖ A table of the characteristic animals and plants, of four sub-zones, is given in Professor Forbes' Memoir on the Geological Relations of the existing Fauna and Flora of the British Isles.—*Memoirs of the Geological Survey of Great Britain*, vol. i., p. 373.

the mollusca, the genera *Lacuna* and *Rissoa*, the *Patella pellucida* and *lævis*, *Pullastra perforans* and *vulgaris*, and various *Modiolæ* are especially characteristic of this zone, and numerous zoophytes and *Radiata*, especially *Echinus sphæra*, *Tubularia*, *Actinea senilis*, though ranging both higher and lower, are more prolific here than in any of the other regions." Lastly comes the *Nullipora*, bounding the marine vegetation in depth, and rarely ranging down to more than 120 feet in our seas.*

The region of corallines is so termed from the greatest abundance of corneous zoophytes, which appear to take the place of plants, being found in it. The carnivorous mollusca are abundant, species of *Fusus*, *Pleurotoma*, and *Buccinum* are common, and many species of *Trochus* are found; *Naticæ*, *Fissurellæ*, *Emarginulæ*, *Velutinæ*, *Capulus*, *Eulimæ*, and *Chemnitziæ* are abundant; and among bivalves, *Artemis*, *Venus*, *Astarte*, *Pecten*, *Lima*, *Arca*, and *Nucula*. "Numerous and peculiar *Radiata*, including the largest and most remarkable species, abound, and for number, variety, and interest of the forms of animal life in the British seas, this region transcends all others."† This zone extends from about 90 to about 300 feet, its greatest development being between 150 and 210 feet.

The fourth region is that of deep-sea corals, and is local. The greater part of the area of the British seas does not attain the depth at which this zone commences. Professor E. Forbes considers this region as hitherto but very partially explored. "As far as we know," he observes, "it is well characterized by the abundance of the stronger corals, the presence in quantity of species of the *Dentalium*-like genus of *Annelides*, called *Ditrupa*, by a few peculiar *Mollusca*, and by peculiar *Echinodermata*, as *Astrophyton* and *Cidaris*, and *Amorphozoa*, as *Tethya cranium*. All our British *Brachiopoda* inhabit this zone, and probably range throughout it."‡

* Professor E. Forbes points out, that the Nullipora likewise bounds marine vegetable life in the Mediterranean, where it descends to 420 and 480 feet. With respect to the depths to which marine vegetable life extends, he remarks, that it does so further than is commonly supposed, stating that in the Eastern Mediterranean, *Codium flabelliforme* is found at 30 fathoms, *Microdictyon* at 30 fathoms, *Rityphlæa tinctorea* at 50 fathoms, *Chrysymenia uvaria* at 50 fathoms, *Dictyomenia volubilis* at 50 fathoms, *Constantinea reniformis* at 50 fathoms, and *Nullipora polymorpha* at 95 fathoms, (570 feet).

† Forbes, Mem. Geol. Survey of Great Britain, vol. i., p. 374.

‡ Professor E. Forbes remarks respecting the Brachiopoda, that when found, in certain localities, in more shallow water among the corallines, there are reasons for believing that their occurrence there may be explained by geological changes affecting the conditions of the sea bottom.

[We

The advance thus made will be sufficient to stimulate other observers, so that at no very distant period a valuable mass of evidence may be anticipated.* Probably the general views, based on the local investigations above noticed, may be found capable of extensive application. However this may be, it can scarcely but happen that an accumulation of additional data would most materially aid the progress of the geological inferences to be deduced from the mode of occurrence of organic remains in rocks.

With respect to the littoral zone, that most influenced by climate, while in tideless seas or those where tides are of little consequence, the marine animals inhabiting it are under conditions of slight change, as regards the vertical rise and fall of water; in tidal seas the case is different. In tidal seas many littoral molluscs are exposed to atmospheric influences for different periods, those near high-water mark the longest; so that while the latter may remain uncovered by water six or eight hours at a time, those nearer low-water mark may be so for only an hour or two, some merely for a short time at spring tides. Neap tides also leave a belt surrounding land, the higher part of which is only covered by water for a few days at a time, and then only at spring tides. It thus happens that while in the tropics the littoral zone may not be under very material changes of temperature during the year, this condition, looking at the subject as a whole, gradually shades off on either side towards the polar regions, where the water becomes solid along shore for part of the year, and the coasts are often only partially clear in the summer, portions being still

We would refer for a valuable view of the characteristic plants and animals inhabiting the four zones into which the area of the British seas has been divided, to the table given by Professor E. Forbes, in his Memoir on the Geological Relations of the existing Fauna and Flora of the British Isles, Memoirs of the Geological Survey of Great Britain, vol. i, p. 375.

* When we recollect that under favourable circumstances the officers of our Navy and of our Merchant Service, may render great assistance to this inquiry, when properly conducted, it is to be hoped that we may eventually obtain, through their exertions alone, more extended facts connected with the subject. Under their care the dredge might often be applied with advantage; and if specimens of the animals obtained were stowed away safely, properly ticketed, for the examination of competent naturalists, far more would be known in the next half-century touching the distribution of marine life, particularly at depths where surface waves could not so act as to drive its remains on shore, than could be accomplished by naturalists alone, however zealous.

During the surveying voyage of H.M.S. Rattlesnake, commanded by the late Captain Owen Stanley, R.N., on the coast of Australia and New Guinea, numerous valuable observations were made upon the distribution of marine animals in depth, and an account of the zones of life, in the regions explored, is contained in the "Narrative" of the voyage by Mr. Macgillivray.

subject to the occasional pressure of floes and masses of ice. In certain intermediate regions all animals and plants inhabiting the distance between high and low water mark, with its modifications according to the state of the tide, must be adjusted to sustain the extremes of a long range of temperature, in order to support the atmospheric changes to which they are exposed. The differences of temperature observable round the British Islands, notwithstanding the advantage of their position, are sufficiently considerable to produce a movement among many marine animals, as is well known, so that certain of them are only seen close in shore, among the pools left by the tide, in the warmer season. Others again appear organized to sustain a considerable change of temperature. We have seen the common limpet (*Patella vulgaris*) apparently doing well on our coasts, at temperatures of 92° (close to the rock), and of 24°, a range of 68°. As far, therefore, as temperature is concerned, such a mollusc could live in the ocean waters, and at any depths, in all parts, except in the higher portions of the sea during the winter months in the icy regions. Its organization is no doubt adjusted to a littoral life, and to changes of temperature, as part of the littoral conditions in such climates as that of the British Islands, but the amount of change which it can in this manner support, may make us careful at giving too much importance to temperature alone in the distribution of marine animal life. Once beneath a moderate depth of sea, the mass of water is less acted upon by atmospheric influences, and the adjustment to the specific gravities of water at different temperatures is such as to produce much uniformity in the temperature of the deeper zones, and minor modifications in those above them; in the warmer regions tending to keep the sea temperature beneath that of the atmosphere, and in the colder to raise that of the water above it. As, therefore, the sea level is approached, so as a whole must the animals inhabiting the higher zones be adjusted to support changes in the temperature of the sea in those regions where the summer differs materially from the winter as regards heat.

Quitting coast conditions, and regarding the ocean beyond the depths of 200 or 300 fathoms, we have a large area, on the bottom of which we have no reason to suppose any vegetation exists, seeing that observations on coasts would lead us to conclude that the needful conditions for its growth terminate at comparatively very minor depths. All phytophagous marine creatures would not be expected beyond their ability to obtain the food fitted for them,

while the carnivorous animals have necessarily the power to extend vertically and horizontally, far beyond the growth of marine vegetation, however this vegetation may support the mass of life upon which the carnivorous animals have, as a beginning, to feed. In the region of the Sargasso weed, we have an example of a floating vegetation, tending to support animal life, and forming the abode of multitudes of marine creatures in the open sea. This, however, is an exception to the general fact of the absence of marine vegetation in the open ocean, except so far as stray portions of sea-weed, borne by currents from coasts, may be concerned.

In the oceanic depths there exist, apparently, conditions under which some portions of the remains of the fish, crustaceans and molluscs, to be found on the surface above, may be preserved. Although much may be consumed and continued in the mass of life so inhabiting the surface, from time to time some part of the harder portions of animals may descend to the bottom, assuming that the specific gravity of such remains be such as to permit their fall through the water.* Shells of the *Ianthina communis,* having a specific gravity of 2·66, and of the *Nautilus umbilicatus* with that of 2·64, would, after the fleshy matter of these molluscs was decomposed or consumed, and no air entangled in the interior of the shells, be capable of descending to any depths which we may consider at all probable in the ocean, supposing its saline contents not to materially differ in depth, and the compressibility of sea water such as experiments upon fresh water would lead us to infer. We may thus have the remains of marine animals scattered over the bottom of the ocean floor, in certain localities especially, as also those of stray animals drifted from coasts, attached to seaweeds or pieces of wood, both of which decomposing, the harder portions of these animals may fall to the bottom at great depths. It can scarcely be supposed that all the logs of wood bored by the Teredo, or covered over by the common barnacle, *Anatifa striata*, are drifted on shore, and that they do not often become so decomposed as to permit the descent of the harder parts of these animals to the bottom. Indeed we might anticipate a somewhat singular

* With respect to the compressibility of the ocean waters; according to Poisson (Nouvelle Théorie de l'Action Capillaire, p. 277) it would require a pressure equal to 1100 atmospheres to reduce water six-hundredths of its volume. In the experiments of MM. Colladon and Sturm, water not deprived of air, was compressed equal to 47·85 millionths for each atmosphere, and deprived of air, equal to 49·65 millionths. The expériments of M. Oersted gave a compression of 46·65 millionths for each atmosphere. Water containing salts in solution was found, as might be expected, somewhat less compressible.

mixture of the harder parts of some marine animals in different parts of the ocean, especially in the vicinity of islands rising out of considerable depths, such, for example, as near Hawaii, Mani, and other islands of the Sandwich group.

Returning to the coast, we find with the animal life the vegetation on which it feeds, from that exposed to the atmosphere at low water, on tidal shores, to that only known by dredging and fishing. Those accustomed to examine the rocky shores of tidal seas well know how much sea-weed may be cast on shore in the little bays and creeks, or be drifted to the larger bays, during and after heavy gales of wind, producing breakers on such coasts, and which tear up the marine plants, especially towards low-water mark, where during calmer times they may have been abundantly produced. A sandy bay beyond a long line of steep rocky coast, the latter exposed to some heavy gale during the rise and fall of several successive tides, so that sea-weeds, detached by the breakers from it, are driven by wind and tide into the bay, will be often seen by the observer to have its beach covered in various places with matted masses of these plants. Frequently, as might be expected from the forces employed, these lines of sea-weed are cast up high on the beach, beyond the reach of calmer seas to float them off. They will there be disposed of according to the climate. In warm countries, or in the summer months of the temperate regions, they soon decompose, and their remains, not borne off in a gaseous form, become intermingled with the beach. An observer, by studying the sections of sandy beaches exposed by rills or small streams of water, may occasionally find irregular layers of black carbonaceous matter, the result of the decomposition of masses of sea-weeds cast on shore, intermingled with the ordinary sand, and in some localities, parts of a shingle beach will be seen with an abundance of intermixed sea-weed in a decomposed or decomposing state. He may also find the light matter of decomposed sea-weeds borne to deeper waters in sheltered situations, its entombment in such places depending upon the disturbance to which it may be subsequently exposed, and the amount of ordinary sedimentary substances which may collect permanently over it. In some localities much mud, black with carbonaceous matter thus derived, may be accumulated.

Molluscs, living among the sea-weeds thus detached and cast on shore, are occasionally observed to be entangled amid the plants, their harder parts remaining intermingled with the sands or shingles after the decomposition of the plants, so that the shells of rock-

frequenting molluscs become embedded with those of others living in and upon sands. The little *Patella pellucida* is very commonly thrown on shore on our coasts, adhering to the cavity it has made for itself at the root of some large fucus, and which, indeed, has weakened the power of the plant to keep its place, when acted on by the sea in heavy gales. It is also very common to find drifted marine creatures of other kinds entangled in these masses of detached sea-weeds; on some coasts the remains of crustaceans being abundant.

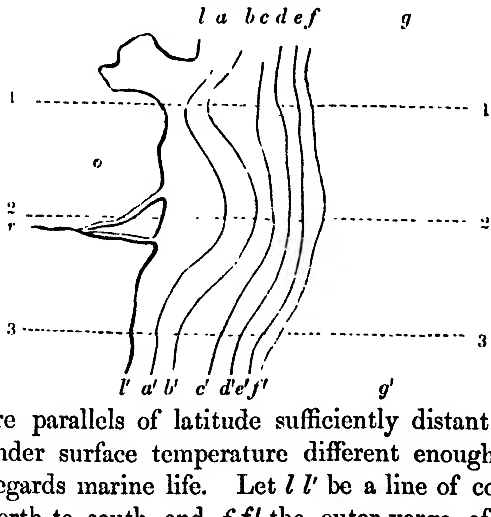
With regard to steep coasts, vertical or nearly vertical cliffs plunging suddenly into deep water, it may happen that molluscs, feeding upon marine plants growing at various depths, and themselves inhabiting different depths, according to their kinds, get knocked off by the sea. While those uninjured may again recover their positions, a few perish, and their shells be preserved in sand, silt, or mud, with the remains of other molluscs living on such bottoms; so that the remains of littoral, shallow, and deep-water molluscs become preserved together in the same deposit. Molluscs as they die must have their shells washed away by the sea on such coasts, and thrown into deep waters. Some account has also to be taken of birds picking the animals out of shells which they may have obtained upon the rocks at low tide, or have brought from adjacent bays where they may have been cast alive or recently killed on shore. We have seen the common oyster-catchers busy knocking off and eating limpets upon projecting portions of steep coasts, leaving the shells, all of which, when there is breaker action, must have been washed into deep water as the tide rose. Such circumstances have to be considered upon the steep coasts of the world, of which there is no want, many fathoms of depth being found, with occasionally a few projections in different places, close along shore, various marine vegetables and animals occupying zones of the depths best suited to them. The sea adjoining some of the ocean islands, where great depths are obtained all round, may, perhaps, afford some of the best conditions for collecting together the remains of marine life which had inhabited different zones of depth.

While the remains of marine animals which have existed in different zones of depth, with the modifications due to sheltered and exposed situations and other variations of conditions, may be collected either in the immediate vicinity of, or at no great distance from, steep coasts, it is in tidal seas, to the fringes of detrital or chemically-formed matter around the chief masses of land, rising

above the sea, that we look for the preservation of the great amount of organic remains. Indeed, the modifications of the actual coasts as to depth, are commonly but variations of the manner in which these submarine fringes join the subaërial portions of the solid land. Such fringes may be regarded as forming extensive plains on the margins of tidal seas (here and there a projecting mass of rock rising above them), with usually a somewhat gentle slope to the depth of 600 to 1000 or 1200 feet, after which they often appear, as a whole, to descend more abruptly. Gentle as the slope may be, the differences of depth appear sufficient, as above stated, for the modification of life upon it, so that while some animals live near the coast, others keep far out in the deeper water. While some portion may be enabled to live at varied depths, there exists a mass of life, the remains of which would be entombed far from shore in one case, and near it in the other, and not commingled, as in the case of steep coasts, and adjoining deep seas. A glance at the charts of a large portion of the eastern side of the American continent will show how far separated, horizontally, such masses of remains may be.

Let it, for illustration, be supposed that the following map (fig. 69) represents an extended line of coast, so that 1, 1; 2, 2;

Fig. 69.



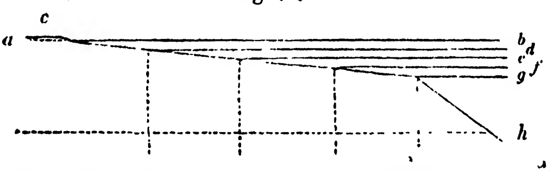
and 3, 3, are parallels of latitude sufficiently distant from each other to render surface temperature different enough to be important as regards marine life. Let *l l'* be a line of coast extending from north to south, and *f f'* the outer verge of about 100 fathoms off the same coast, a more sudden increase of depth taking place at this depth into the area *g g'*; equal depths, or zones being represented by the lines *a a'*, *b b'*, *c c'*, *d d'*, and *e e'*.

For still further illustration, we have supposed a large river (*r*)

to deliver itself upon the coast. Upon such a subaqueous area, we have the conditions for the entombment of the remains of the life distributed over it in certain bands, coinciding with depths ranging in lines with the coast, and with the power of tidal and wave action upon the detritus thrust forward by, or carried in mechanical suspension out of, the river, in addition to any sedimentary matter directly obtained from the coast. The effect of the river waters in rendering the shore water brackish would vary in depth, according to circumstances, the tendency of such waters, from their relative specific gravity, being to float above the sea water, and not to be much mingled with the latter to any great amount of depth, though, upon the ebb tide, brackish water might be carried along shore if the tide took that course. Different states of the weather would modify the conditions for the mixture of fresh and sea waters. Thus during heavy on-shore gales of wind, and freshets in the rivers, as are often combined on the western portions of the British Islands, the conditions for mingling sea and river waters would be more favourable than during calm weather.

Let us suppose the following section (fig. 70) to represent (though upon a very exaggerated scale) that of the map (fig. 69),

Fig. 70.



a b being the sea-level, *c*, coast, *d*, *e*, *f*, *g*, different depths of sea, and *h*, the more sudden descent into deep water. In tideless seas these various depths would remain undisturbed, except by movements arising from the waves produced by the winds above, unless, indeed, there be currents acting in such seas. In tidal seas the case would be so far different, that the level of the sea itself would be altered during every tide; on some coasts making a change of many feet. With this change of level, any motion in the waters produced by waves above would also descend more or less deep, supposing equal wave action on the surface. In addition, the sweep of the tidal stream will extend to the depths it may, according to conditions, reach, and occasionally an ocean current may range sufficiently near a coast to act on the bottom, the shores of ocean islands sometimes offering conditions for the latter. We have now to consider that while the shells of molluscs would often

remain in the mud, silt, or sand which the animals may frequent, penetrating into them to various depths, according to their habits, so that such remains are preserved after their death in the position usually occupied by the molluscs, numerous other shells remain on the surface to be acted upon in the manner of any inorganic substance.

That shells are so scattered about, multitudes brought up by the arming of the sounding-lead abundantly attest. Moreover, collections of certain species are found to mark particular portions of soundings off given coasts. Thus off the shores of the British Islands, charts give localities as marked by *Hake's teeth,* as they are termed; commonly nothing else than a multitude of the shells of *Dentalium* scattered over particular areas. Other collections of shells are equally well known. While these shells, scattered over the sea bottom, are often either the entire hard parts of univalves, or single and uninjured valves of the bivalves, at other times they are crushed or broken. Whether in the one state or the other, according to their specific gravities, volume, and form, they will be acted upon by streams of tide, by ocean currents sweeping within sufficient depths, or by surface wind-wave action transmitted to the bottom. With respect to specific gravities, though there is apparently much variation in this respect, the floating molluscs being, some of them at least, provided with shells of comparatively minor specific gravity, the range seems something between 2·67 and 2·85*. With equal forms and volumes, fragments or rounded grains of a great proportion of marine shells would apparently be specifically heavier than grains of quartz and rock crystal (2·63—2·65), of common felspar (2 53—2·60), of albite (2·61—2·68),

* The author obtained the following specific gravities of a few marine shells some years since.—Researches in Theoretical Geology, 1834, p. 76.

Argonauta tuberculosus	2·43	Chiton	2·79
Nautilus umbilicatus	2·64	Pholas crispata	2·82
Ianthina communis	2·66	Cytherea maculata	2·83
Lithodomus dactylus	2·67	Bulla	2·83
Teredo (great, East Indies)	2·68	Voluta musica	2·83
Haliotis tuberculatus	2·70	Cassis testiculus	2·83
Cyprina vulgaris	2·77	Strombus gibberulus	2·83
Mytilus bilocularis	2·77	Pyrula melongena	2·84
Strombus gigas	2·77	Tellina radiata	2·85

It is not improbable, that if experiments on this head were much multiplied, individual differences would often be found in the same species. While the shell of the *Argonauta tuberculosus* is lighter than pure Sussex chalk (2·49), and that of *Haliotis tuberculatus* is equal in specific gravity to Carrara marble (2·70), the greater numbers exhibit a packing of particles more approaching Arragonite.

and of chlorite (2·71), while they would be lighter than mica (2·94).

The forms of shells or their fragments, except they have been ground down to rounded grains by breaker action on beaches, commonly agree little with those of the sedimentary matter among which they lie superficially mixed. When, therefore, we have to regard any movement of water around whole shells or their fragments, their forms become important, as also the mode in which they may be exposed to any moving force employed. Thus the same shell, if a conical univalve, would offer a different resistance, according as it might be placed with its apex or its base to the moving water, when acted upon, though we might expect that the moving water would soon turn such body, so that its apex would be presented to the line of action. With the valve of a bivalve, its hold on a bottom of sand or silt would be very different, whether it were turned with the margin of the valve downwards, or merely rested upon some part of its bombed surface. How far the valve of a shell could be transported along the bottom without being upset, will depend on very obvious conditions. In all cases we have to consider that shells, or their fragments, having a specific gravity rarely, perhaps, exceeding 2·85, and often presenting forms readily moved, are not difficult of transport in a medium of the specific gravity of 1·027—1·028.

Referring to the plan and section above given (figs. 69 and 70), the observer will have to distinguish between the remains of those molluscs which may die amid the mud, silt, or sand, and so have their harder parts preserved in the situations where they live, and the remains on the surface of the sea bottom. How far these may retain their positions relatively to the zones of depth suited to their animals, will depend upon the circumstances above noticed. Looking at the subject generally, they would be liable to be moved at the depth at which surface-wave action could reach, and therefore to be moved shorewards in shallow waters; so that the remains of molluscs accumulated near the coast in the zones *b a l*, *b′ a′ l′* (fig. 69), varying in the depths *b d*, *d e* (fig. 70), would, at the proper depths, have surface-wave action added to tidal streams able to transport the shells or their fragments, tending to move them on-shore. In the outer zone *e f* (fig 69), and at the depths *f g* (fig. 70), the effects of the tidal movement may not only be little felt, but also any action upon the bottom from surface-waters be inappreciable. Still further out, in the deep waters *g* (fig. 69), or *h* (fig. 70),

there may be no movement sufficient to produce transport of loose matters on the bottom. There might, therefore, be movements in the water producing considerable mixtures of the remains of molluscs in shallow situations, extending even to the casting of shells or their fragments upon the shore, from depths depending upon various local modifications of the causes of transport above noticed.

On many exposed ocean-coasts we have even the accumulation of sandy dunes, composed, for the most part, of fragments of mollusc shells ground down to sand, these cast on shore and dealt with by winds in the manner of common sand. The western coasts of Ireland, Scotland, and of part of England, afford many examples of this fact.*

The induration of sands formed of comminuted shells has been previously mentioned (p. 62), and, as may be expected, such indurated sands occasionally include remarkable mixtures of organic remains. The rock in which the human bones were discovered at Guadaloupe would appear to be of this character. Not only corals and shells from the neighbouring sea, but terrestrial shells also, including the *Bulimus guadaloupensis* (Ferussac), are preserved in it. Teeth of the caiman, with stone hatchets and other remains of human art, are mentioned as having been found in this consolidated sand.

The study of the manner in which the shells of molluscs, and the harder parts of marine animals generally, are thrown on shore, of the depths from which they may be borne by the action of on-shore waves and breakers, and of the various arrangements of whole, broken, or comminuted shells in layers, from their accumulation like ordinary detrital matter at various depths in the sea to their rejection upon the land, is one which will amply reward the observer anxious to compare the manner in which these remains are now distributed and arranged with that of the organic remains found in fossiliferous rocks. He may at times see the

* This shell sand is often employed as manure; it is known to have been so employed in Cornwall in the reign of Henry III. A charter of Richard, King of the Romans, granting the liberty of taking this sand for manure, was confirmed by Henry III. (Lysons, "Mag. Brit.," Cornwall, p. ccciii, who cites Rot. Chart., 45 Hen. III.) Carew notices the use of it in his Survey of Cornwall (1602), and it is largely employed for agricultural purposes to the present day. Mr. Worgan, in 1811, estimated the cost of the land carriage of this sand in Cornwall at more than 30,000*l*. per annum. Large quantities are obtained at the Dunbar Sands, in Padstow Harbour, the annual amount estimated at 100,000 tons. It has been calculated that 5,600,000 cubic feet of sand, chiefly composed of comminuted sea-shells, are annually taken from the coasts of Cornwall and Devon, and spread over the land in the interior as a mineral manure.—Report on the Geology of Cornwall, Devon, and West Somerset (1839), p. 479.

pushing action of the small wash of the sea driving the larger shells and their fragments before it into convenient localities, there accumulating in a mass those which may have been distributed by breaker action along a line of coast, while at others he will find the shells jammed in amid the joints and crevices of rocks so firmly that they become difficult to remove.

CHAPTER X.

CORAL REEFS AND ISLANDS.—DISTRIBUTION OF CORAL ANIMALS.—CHEMICAL COMPOSITION OF CORALS.—KEELING ATOLL.—FORM OF CORAL ISLANDS.—BARRIER REEFS.—LAGOON ISLANDS.—ISLE OF BOURBON.

GREAT as the accumulations of the harder remains of molluscs may be in the sea or on its shores (and regarding the amount of matter, chiefly calcareous, abstracted from the sea or contained in their food the volume of these harder remains added annually to common detrital and chemical deposits must be very considerable), the coral accumulations of tropical regions present us with the most striking additions, by means of animal life, to the mineral deposits now in progress. They have for many years attracted the attention of navigators and naturalists, so that much information has been obtained respecting them.*

With regard to the distribution of corals, Mr. Dana states, that the *Astræacea*, *Madreporacea*, and *Gemmiporidæ* among the *Caryophyllacea*, are, with few exceptions, confined to the coral-reef seas, a region included between the parellels of 28° north and south of the equator,† these corals forming the principal portion of the reefs, and being confined to depths within 120 feet from the surface. Other corals, as is well known, extend to far greater depths, and into colder regions. Sir James Ross, in his voyage to the South Polar Regions, obtained live corals from a

* We would more especially call attention to the labours of Mr. Darwin, who has not only been personally engaged in the investigation of coral reefs and islands, but has also carefully studied the works of navigators and naturalists relating to the subject. The results of his investigations are contained in his work, entitled, "Structure and Distribution of Coral Islands," London, 1842. We would also refer to the labours of Mr. Dana, contained in his "Structure and Classification of Zoophytes," Philadelphia, 1846. Mr. Dana's views are also founded on the personal examination of coral reefs and islands.

† Locally, coral reefs are found further north and south than 28°. They extend in the Bermuda Islands to lat. 32° 15′ N., the greatest distance from the equator, as Mr. Darwin observes, at which they are known to exist, and to lat. 30° N. in the Red Sea. Houtman's Abrolhos, on the western shores of Australia, in lat. 29° S., are of coral formation.

depth of 1620 to 1800 feet off Victoria Land. Mr. Charles Stokes notices a species of *Primnoa* (*lepadifera*), as found from 900 to 1800 feet off the coast of Norway; and Professor E. Forbes a species of the same genus from a depth of 1668 feet off Staten Land.* As respects the range of corals, Mr. Dana observes that "*Caryophyllidæ* extend from the equator to the frigid zone, and some species occur at the depth of 200 fathoms or more. The *Alcyonaria* have an equally wide range with the *Caryophyllidæ* and probably reach still higher towards the poles. The *Hydroidea* range from the equator to the polar regions, but are most abundant in the waters of the temperate zone."† Regarding the distribution of species, Mr. Dana states, that of 306 species, 27 only are common to the East Indies and Pacific Ocean, while only one species, and that with doubt (*Meandrina labyrinthica*), is considered to be common to the East and West Indies.‡

Mr. Darwin remarks on the entire absence of coral reefs in certain large areas in the tropical seas. No coral reefs have been found on the west coast of South America, south of the equator, or round the Galapagos Islands; neither have any been yet noticed on the west coast of America, north of the equator. In the central parts of the Pacific there are islands free from coral reefs, and there do not appear to be any coral reefs on the west coast of Africa, or round the islands of the Gulf of Guinea. St. Helena, the Cape Verde Islands, St. Paul's, and Fernando Noronha are also without such reefs.§

Regarding the occurrence of corals as a whole, we thus see that they may be more or less strewed over a very large submarine area, one extending from the polar to the equatorial regions, some of them keeping to small depths within a portion of the general area comprised between the parallels of 28° north and south of the equator, and even rising to the surface of the sea in certain parts of that minor area. However great occasional accumulations of their harder parts may be, under favourable conditions elsewhere, concealed beneath the ocean waters, we have

---

* Sir James Ross, "Voyage to the Antarctic Regions."

† "Structure and Classification of Zoophytes."

‡ Referring to the causes of distribution and original sites, or centres of distribution, Mr. Dana observes:—"There is sufficient evidence that such centres of distribution, as regards zoophytes, are to be recognized. The species of corals in the West Indies are, in many respects, peculiar, and not one can with certainty be identified with any of the East Indies. The central parts of the Pacific Ocean appear to be almost as peculiar in the corals they afford. But few from the Feejees have been found to be identical with those of the Indian Ocean."—"Structure and Classification of Zoophytes."

§ Darwin, "Structure and Distribution of Coral Reefs," pp. 61, 62.

in the masses of dead and living corals which constitute islands and reefs, enough to show the geological importance of these animals, which thus, from their food and the surrounding waters, secrete a mass of matter constituting rocks, so acted upon, under fitting condition, by the breakers and by atmospheric and chemical influences, that dry land rises sufficiently above the sea to support terrestrial vegetation and animal life.

It would appear that the calcareous secretions* of corals only begin to be formed after the last metamorphosis of the young animal, one effected when it quits the swimming state and attaches itself to some support. Until that time the young can move, by their own powers and the transporting action of tidal streams or oceanic currents, to situations where, under the needful conditions, they can settle and flourish as perfect corals. No doubt myriads of the young animals perish, or are consumed as food, so that a part only is available for supplying the loss by death of the old stock, for increasing the amount of coral life in localities where it previously existed, or for the formation of new colonies. Under all such circumstances, if there be no cause producing a removal of the harder parts of the corals after the death of the polyps which secreted them, they will accumulate. Portions of the harder parts would appear to be destroyed by the animals which feed upon or bury themselves among the corals while living, others are broken off by the action of the sea, and some would appear to be taken up in solution. In the first case, the portion not required for the harder parts of the animals feeding upon the corals appears to be thrown down with their fæces amid the coral reefs; in the second, the fragments torn off by the breakers are distributed, like any

* Dana, "Structure and Classification of Zoophytes," p. 52. Speaking of the mode in which the secretions are formed, Mr. Dana observes:—"In a *Madrepora* the surface between the cells becomes covered by minute points by the continued secretions, and then a layer forms, connected with the preceding, by these points or columns. The interior usually becomes, afterwards, nearly solid by additional secretions. This variety of structure may be observed also in the *Dendrophyllia*; and even the compact species, in which there are no traces of cellules, will often show evidence of having been deposited in layers. I have seen it brought out with singular distinctness, in a specimen half fossilized. In many corals, however, we fail to detect this deposition in layers. This is the case in the *Astræa* tribe. The *Pocilloporæ*, and some allied corals, have transverse plates crossing the cells internally, which are intermitted secretions from the lower part of the polyp; but no appearance of layers has been detected in the spaces between the cells. The *Favosites*, and many *Cyathophyllidæ*, are examples of similar interrupted secretions across the cells," (p. 53.)

Respecting the foot secretions, he remarks:—"The foot secretions appear to be entirely independent of the tissue secretions. The former are often horny when the latter are calcareous, and when they occur together they constitute separable layers, one enveloping the other. The united polyps of a branch have their mouths opening

other detritus, also among the reefs; and in the third, the part not appropriated by the living corals, or by other animals, for their harder parts, appears to be deposited amid the matter of the reefs, tending to bind them together, and adding to their solidity.

From the chemical researches of Mr. B. Silliman, who analysed numerous specimens of calcareous corals sent him by Mr. Dana, it would appear that, after the animal matter had been separated, carbonate of lime formed from 97 to 99 per cent. of the inorganic matter which remained; 1 to 3 per cent. being composed of silica, lime (probably united with the silica), carbonate of magnesia, fluoride of calcium, fluoride of magnesium, phosphate of magnesia, alumina, and iron.* The animal matter varied from 2·11 to 9·43 per cent. From many analyses of corals made at the Museum of Practical Geology, London, carbonate of lime was found to range from 82 to 95·5 per cent., carbonate of magnesia from a mere trace to 7·24 per cent., sulphate of lime from a trace to 2·76 per cent., and organic matter from 3 to 8·27 per cent. Silica, alumina, iron, phosphates, and fluorides were also obtained as in the analyses of Mr. Silliman. As a mass, therefore, we may regard the hard matter secreted by the coral polyps of a reef as chiefly formed of carbonate of lime, mingled with animal matter, of occasionally a notable quantity of carbonate of magnesia, with a minor per centage of other substances, among which are found fluorine and phosphoric acid.

The young of the reef-making coral polyps attaching themselves where the needful conditions obtain,† and according to the habits and requirements of each species, it becomes important to learn how far these may differ, and yet each species aid in building up the general mass of a reef. Mr. Darwin's detailed description of Keeling, or Cocos atoll, situated in the Indian Ocean in lat. 12° 5' S., affords a valuable view of the manner in which the

outwards on every side, while the bases are directed inward towards a common central, or axial line. The simultaneous secretions of the bases, therefore, must necessarily produce a solid axis to the branch," p. 54.

* Dana, "Structure and Classification of Zoophytes," pp. 124—131.

† Respecting the needful conditions for the establishment and distribution of reef-making corals, Mr. Couthouy (Boston Journal of Natural History, vol. iv., 1842, and American Journal of Science, vol. xlvii., 1844,) and Mr. Dana (American Journal of Science, vol. xlv, 1843), independently of the views of each other, refer to the temperature of the sea rather than to its depth, as limiting the range of the reef-making corals, and attribute the absence of coral reefs in the inter-tropical and eastern portions of the Atlantic and Pacific to the influence of the cool and extra-tropical currents which there set in. Mr. Dana limits the distribution of the reef-forming corals to a temperature of, and above, 60° Fahr.; and Mr. Couthouy considers that they thrive best in water, at a temperature of between 76° and 80° Fahr.

various corals forming a reef in those seas are adjusted. Having, under favourable circumstances, reached the outer edge of the reef, where the coral was alive, he found that it was almost entirely composed of living porites, forming great irregular rounded masses from four to eight feet broad, and little less in thickness. On the furthest mounds which he reached, and over which the sea broke with some violence, the polyps in the upper cells were dead, but three or four inches lower down they were living. In consequence of the check given to their growth upwards, the corals extended laterally. Further outwards the porites were all seen to be alive. Next in importance is the *Millepora complanata*, growing in thick vertical plates, and forming a strong honeycomb mass, generally of a circular form, the marginal plates being alone alive. Between these plates, and in the crevices of the reef, a multitude of zoophytes and other productions flourish, protected by the porites and millepora from the breakers. Masses of living coral, apparently similar to those of the margin, descend very gradually outwards to the depth of 60 or 70 feet. The arming of the sounding lead brought up fragments of *Millepora alcicornis* within these depths, and there was an impression of an astræa, apparently alive. Examining the fragments thrown on shore by the breakers, the porites and a madrepore, apparently *M. corymbosa*, were the most common; and as this coral was not found alive in the hollows of the reef, Mr. Darwin concludes that it must occur abundantly in a submerged zone outside. Between the depth of 72 and 120 feet the arming of the lead came up an equal number of times marked by sand and coral. Beneath 120 feet sand was obtained. After the depth of 150 feet the outward sides of the reef plunged, at an angle of 45°, into the sea, the depth of which was not found at 2200 yards from the breakers, with a line of 7200 feet in length.*

Close within the outer margin of the reef, where the coral life ceases, three species of nullipora flourish, either separately or mingled together, forming by their successive growth a layer two or three feet in thickness, of a reddish colour. This layer fringes the reef for about 20 yards in width, constituting a continuous

* Darwin, "Structure and Distribution of Coral Reefs," pp. 6—8. "Out of 25 soundings," observes Mr. Darwin, "taken at a greater depth than 20 fathoms, every one showed that the bottom was covered with sand; whereas, at a less depth than 12 fathoms, every sounding showed that it was exceedingly rugged, and free from all extraneous particles. Two soundings were obtained at the depth of 360 fathoms, and several between 200 and 300 fathoms. The sand brought up from these depths consisted of finely-triturated fragments of stony zoophytes, but not, as far as I could distinguish, of a particle of any lamelliform genus: fragments of shells were rare."

"At a distance of 2200 yards from the breakers, Captain Fitzroy found no bottom with a line of 7200 feet in length; hence the submarine slope of this coral formation

smooth convex surface, when the corals are united into a solid margin, and forming a protecting breakwater.*

The form of this atoll will be seen by the subjoined plan, (fig. 71.) † The reef is broken by two open spaces, through

Fig. 71.

one of which ships can enter; it varies from 250 to 500 yards in breadth, with a level surface, or one very slightly inclined towards the interior lagoon, and at high tide the sea breaks entirely over

is steeper than that of any volcanic cone. Off the mouth of the lagoon, and likewise off the northern point of the atoll, where the currents act violently, the inclination, owing to the accumulation of sediment, is less. As the arming of the sounding-lead from all the greater depths showed a smooth sandy bottom, I at first concluded that the whole consisted of a vast conical pile of calcareous sand; but the sudden increase of depth at some points, and the circumstance of the line having been cut, as if rubbed, when between 500 and 600 fathoms were out, indicate the probable existence of submarine cliffs," pp. 8—9.

* "These nulliporæ," observes Mr. Darwin, "although able to exist above the limit of true corals, seem to require to be bathed during the greater part of each tide by breaking water, for they are not found in any abundance in the protected hollows on the back part of the reef, where they might be immersed, either during the whole or an equal proportional time of each tide. It is remarkable that organic productions of such extreme simplicity, for the nulliporæ undoubtedly belong to one of the lowest classes of the vegetable kingdom, should be limited to a zone so peculiarly circumstanced," p. 9.

† An interesting selection of plans of coral reefs, either surrounding mountainous islands or forming atolls or lagoon islands, among which that of Cocos or Keeling

those parts which do not rise into islets on its surface. *Pocillopora verrucosa* is a common coral in the hollows, as also a madrepore, closely allied or identical with *M. pocillifera.* When the breakers are, by the formation of an islet, prevented from washing entirely over the reef, and channels and hollows are filled up, a hard smooth floor is formed, uncovered only at low water, and strewed with a few fragments torn off during heavy gales. The islets which are formed by an accumulation of fragments, about 200 or 300 yards from the outer edge of the reef, vary in length from a few yards to several miles, with an ordinary breadth of less than a quarter of a mile. On the windward side of the atoll the increase of the islets is by the addition of fragments thrown on their outer sides by the breakers, the highest part thus formed rising from six to ten feet above ordinary high-water mark, and upon this there may be hillocks of blown sand, some of which rise to an elevation of 30 feet. On the leeward side of the atoll, from the sweep of the wind across the lagoon, the little breakers thus formed cast up sand and fragments of thinly-branched coral from the lagoon on the inner sides of the islets in that part of the atoll, thus adding to them inwards. These islands are lower than those to windward, though broader. The fragments beneath the surface are cemented into a solid mass, so as to form a ledge from two to four feet high, from being worked by the breakers acting beyond ordinary high water. Chemical changes take place occasionally among the calcareous fragments thus cemented together, so that the altered coral passes gradually into spathose limestone.*

The lagoon within is necessarily a sheltered situation, and is

Island is one, will be found in Plates 1 and 2 of Mr. Darwin's work on the Structure and Distribution of Coral Reefs; and a most valuable map in the same work, showing the distribution of the different kinds of coral reefs, with the position of active volcanos in the Indian and Pacific Oceans.

* "The fragments of coral which are occasionally cast on the 'flat,' are, during gales of unusual violence, swept together on the beach, where the waves each day at high water tend to remove and gradually wear them down; but the lower fragments having become firmly cemented together by the percolation of calcareous matter, resist the daily tides longer, and hence project as a ledge. The cemented mass is generally of a white colour, but in some few parts reddish from ferruginous matter: it is very hard, and is sonorous under the hammer; it is obscurely divided by seams, dipping at a small angle seaward; it consists of fragments of the corals which grow on the outer margin, some quite and others partially rounded, some small and others two or three feet across; and of masses of previously formed conglomerate, torn up, rounded, and re-cemented; or it consists of a calcareous sandstone, entirely composed of rounded particles, generally almost blended together, of shells, corals, the spines of echini, and other such organic bodies." "The structure of the coral in the conglomerate has generally been much obscured by the infiltration of spathose calcareous matter; and I collected a very interesting series, beginning with fragments of unaltered coral, and ending with others where it was impossible to discover with the naked eye any trace of organic structure. In some specimens I was unable, even with the aid of a lens and by wetting them, to distinguish the boundaries of the

described as much more shallow than those of atolls of considerable size. About half the area consists of sediment, including mud, and half of coral reefs, the corals composing the latter having a very different aspect from those on the outside, and being very numerous in kind.* The sediment from the deepest part of the lagoon was like a very fine sand when dry, though it appeared chalky when wet. Mr. Darwin points out that much fine sediment may be supplied by means of the excrements of the scarus and holuthuriæ, which feed on the coral; large shoals of two species of the former, one of which inhabits the lagoon while the other keeps outside, feeding entirely on the corals, while swarms of various species of holuthuria browse upon the lagoon corals. "The amount of coral yearly consumed and ground down into the finest mud by these several creatures, and probably by many other kinds, must be immense."† The tide flows in and out of the lagoon through the channels, and the latter also carry out the water thrown over the reefs by the breakers.

Thirty-two coral islands in the Pacific Ocean were examined by Captain Beechey;‡ they were of various shapes, and 29 had lagoons in their centres. The dry coral forming islets on the reefs is rarely elevated more than two feet above the sea when divested of any sandy materials heaped upon it, and but for the abrupt character of the outer margin would be inundated by the breakers. Captain Beechey found in the islands seen by him no instance in

altered coral and spathose limestone. Many even of the blocks of coral lying loose on the beach had their central parts altered and infiltrated." Darwin, "Structure of Coral Reefs," p. 12.

Mr. Beete Jukes mentions masses of meandrina, six or eight feet in diameter, turned upside down, and much worn, as torn by the force of the breakers from their places of growth on the weather edge of a coral reef, and driven 200 to 300 yards inwards. "Narrative of the Voyage of the 'Fly,' 1847."

* "Meandrina, however, lives in the lagoon, and great rounded masses of this coral are numerous, lying quite or almost loose on the bottom. The other commonest kinds consist of three closely-allied species of true Madrepora in thin branches; of *Seriatopora subulata;* two species of Porites, with cylindrical branches, one of which forms circular clumps, with the exterior branches only alive; and, lastly, a coral, something like an Explanaria, but with stars on both surfaces, growing in thin, brittle, stony, foliaceous expansions, especially in the deeper basins of the lagoon. The reefs on which these corals grow are very irregular in form, are full of cavities, and have not a solid flat surface of dead rock, like that surrounding the lagoon; nor can they be nearly so hard, for the inhabitants made with crowbars a channel of considerable length through these reefs, in which a schooner, built on the south-east islet, was floated out. It is a very interesting circumstance, pointed out to us by Mr. Leisk, that this channel, although made less than ten years before our visit, was then, as we saw, almost choked up with living coral, so that fresh excavations would be absolutely necessary to allow another vessel to pass through it."—Darwin, "Structure," &c., p. 13.

† Darwin, "Structure of Coral Reefs," p. 14.

‡ "Narrative of a Voyage to the Pacific and Behring's Straits, &c., in the years 1825, 26, 27, and 28." London. 1831.

which the strip of dead coral exceeded half-a-mile from the usual wash of the sea to the internal lagoon. In general it was only 300 or 400 yards. "Beyond these limits, on the lagoon side in particular, when the coral was less mutilated by the waves, there was frequently a ledge, two or three feet under water at high tide, 30 to 50 yards in width; after which the sides of the island descended rapidly, apparently by a succession of inclined ledges formed by numerous columns united at their capitals, with spaces between them, in which the sounding-lead descended several fathoms."* The windward sides of the reefs and islets upon them are higher than the others, the islets not unfrequently well wooded,† while, on the opposite sides, the reefs are "half drowned" or wholly under water. The breaks or entrances into the lagoons generally occur on the leeward side, though they are sometimes found in a side that runs in the direction of the wind, as at Bow Island. The points or angles of the islands were found to descend less abruptly than the sides. The lagoons vary in depth, from 20 to 28 fathoms being found in those which were entered, though the appearance of the water in others would lead to the inference that they were very shallow. The accompanying figures are the sections given by Captain Beechey as affording a general view of these coral islands. Fig. 72 is a section across one about five miles wide; *a a* being dry islets on the reef; *b b*, lagoon; and *c c*, open ocean; and fig. 73 a section across an islet and part of a lagoon, with the slope towards the sea, AB being the habitable part of the island; *a b*, water line; *a h*, general descent seawards towards the points; *a i*, general descent at the points; CC, part of the lagoon; DD, coral knolls in the lagoon; Z, the ocean; *s s s*, soundings on coral.‡

While the coral reefs above mentioned exhibit no traces of rocks

* "Narrative of a Voyage to the Pacific and Behring's Straits, &c., in the years 1825, 26, 27, and 28." Vol. i. p. 256. London, 1831.

† With respect to the vegetation on Bow Island, Mr. Collie mentions that the pandanus and pemphis grow in the sheltered parts of the plain between the ridges; that the loose dry stones of the first ridge are penetrated by the roots of the tefano, which rises into a tall spreading tree, accompanied by the suriana and tournefortia, under the shelter of which the achyranthus and lepidium thrive best. Beyond the first ridge the scævola flourishes. "Beechey's Voyage," vol. i., p. 248. At Ducie's Island the trees are stated to rise 14 feet, making, with the island, 12 feet above the sea, 26 feet from its level. Ibid. vol. i. p. 59.

‡ Captain Beechey gives a more detailed account of Matilda and Bow Islands than of the others. The windward side of the former "is covered by tall trees, while that to leeward is nearly all under water. The dry part of the chain enclosing the lagoon is about a sixth of a mile in width, but varies considerably in its dimensions; the broad parts are furnished with low mounds of sand, which have been raised by the action of the waves, but are now out of their reach, and mostly covered by vegetation.

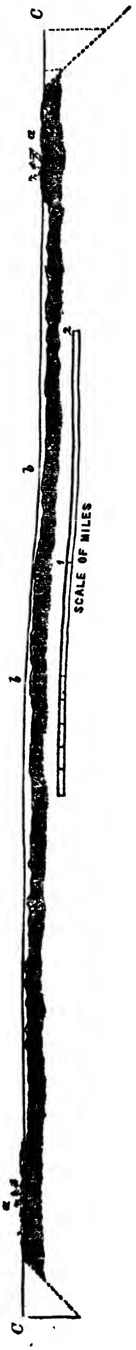

C
a
b
SCALE OF MILES
1
2
C

Fig. 72.

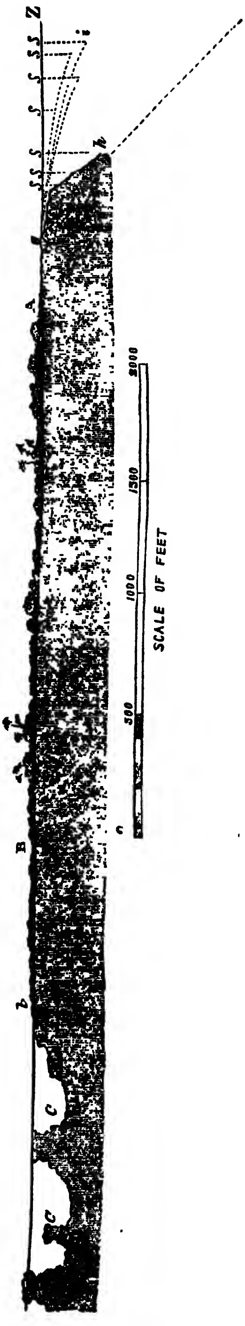

Z
h
A
B
b
C
C
SCALE OF FEET
0
500
1000
1500
2000

Fig. 73.

further than those formed by the consolidation of the matter, chiefly calcareous, secreted by the polyps or derived from it, and distributed chemically and mechanically, other reefs surround islands or groups of islands formed of different rocks, or range along the shores of seas, such as the Red Sea, or those of large masses of land, as on the east coast of Australia. While the reefs

---

The violence of the waves upon the shore, except at low water, forces the sea into the lake at many points, and occasions a constant outset through the channel to leeward.

"On both sides of the chain the coral descends rapidly; on the outer part there is from 6 to 10 fathoms, close to the breakers; the next cast is 30 to 40; and, at a little distance, there is no bottom with 250 fathoms. On the lagoon side there are two ledges; the first is covered by about three feet at high-water: at its edge the lead descends three fathoms to the next ledge, which is about 40 yards in width; it then slopes to about 5 fathoms at its extremity, and again descends perpendicularly to 10; after which there is a gradual descent to 20 fathoms, which is the general depth of the centre of the lagoon. The lake is dotted with knolls or columns of corals, which rise to all intermediate heights between the bottom and the surface." "Voyage," &c., vol. i., p. 218.

"Bow Island is 30 miles long by an average of 5 miles broad. It is similar to the other coral islands already described, confining within a narrow band of coral a spacious lagoon, and having its windward side higher and more wooded than the other, which, indeed, with a few clusters of trees and heaps of sand, is little better than a reef. The sea in several places washes into the lagoon, but there is no passage, even for a boat, except that by which the ship entered, which is sometimes dangerous to boats, in consequence of the overfalls from the lagoon, especially a little after the time of high-water.

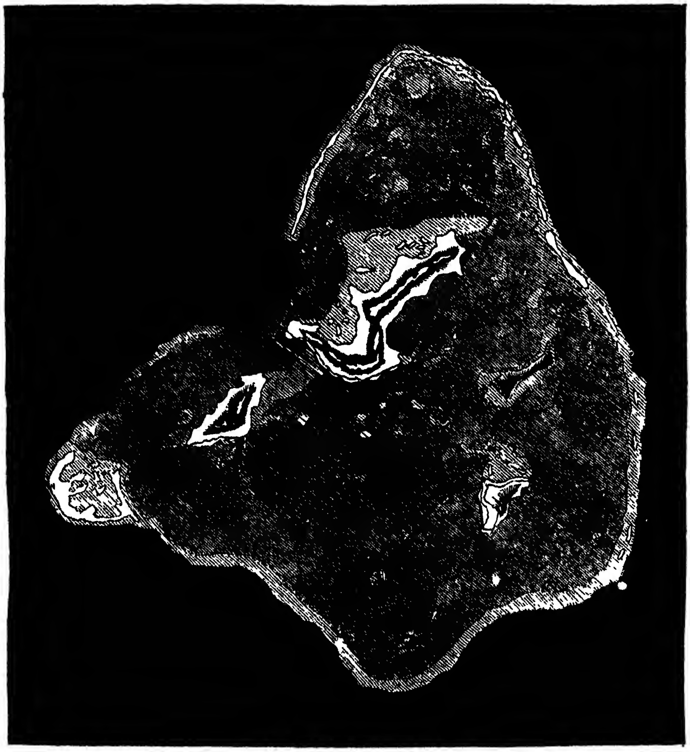
"The bottom of the lagoon is in parts covered with a fine white sand, and is thickly strewed with coral knolls, the upper parts of which overhang the lower, though they do not at once rise in this form from the bottom, but from small hillocks. We found comparatively few beneath the surface, though there are some: at the edge of such as are exposed there is usually six or seven fathoms of water; receding from it, the lead gradually descends to the general level of about 20 fathoms. The height of water in the lagoon is subject to the variations of the tides of the ocean; but it suffers so many disturbances from the waves, which occasionally inundate the low parts of the surrounding land, that neither the rise of the tide nor the time of high-water can be estimated with any degree of certainty. The strip of low land enclosing the lagoon is nearly 70 miles in extent, and the part that is dry is about a quarter of a mile in width. On the inner side, a few yards from the margin of the lake, there is a low bank formed of finely-broken coral; and at the outer edge a much higher bank of large blocks of the same material, long since removed from the reach of the waves, and gradually preparing for the reception of vegetation. Beyond this high bank there is a third ridge, similar to that skirting the lagoon; and outside it again, as well as in the lagoon, there is a wide shelf, three or four feet under water, the outer one bearing upon its surface huge masses of broken coral, the materials for an outer bank, similar to the large one just described." "Voyage," &c., vol. i., p. 245, 246.

Mr. Beete Jukes ("Narrative of the Voyage of the 'Fly' to Torres Straits, &c., 1847") presents us with the following description of one kind of small coral island as seen from the mast-head:—"A small island, with a white sand beach and a tuft of trees, is surrounded by a symmetrically open space of shallow water of a bright grass-green colour, inclosed by a ring of glistening surf, as white as snow, immediately outside which is the rich dark blue of deep water. All the sea is perfectly clear of sand and mud; even where it breaks on a sand beach it retains its perfect purity." "It is this perfect clearness of the water which makes navigation among coral reefs at all practicable, as a shoal with even five fathoms water on it can be discovered at a mile distant from a ship's mast-head, in consequence of its greenish hue contrasting with the blue of deep water."

touch the land in some places, they are removed from it in others; and many present the appearance of the lagoon islands—land either in one mass or in several masses rising through the interior lagoon. Mr. Darwin has classed these various modes of occurrence into atolls, or lagoon islands, barrier reefs, and fringing or shore reefs.*

The following map (fig. 74) of the Gambier's group,† may be taken in illustration of the barrier reefs, and as also showing

Fig. 74.



coral reefs fringing the contained islands. All the interior islands are steep and rugged, Mount Duff, on the largest, rising to the height of 1248 feet, and they would appear to be of igneous origin.‡ The outside reef on the north-east, the windward side,

* We would refer to Mr. Darwin's work, "Structure and Distribution of Coral Reefs," for great detail respecting the different kinds of reefs.

† Reduced from that given by Captain Beechy, "Voyage to the Pacific and Behring's Strait," vol. i.

‡ They are described as composed of porous basaltic lava, sometimes passing into tufaceous slate, at others into a columnar basalt. Dikes cutting the mass were observed.

has portions raised above the sea, bearing trees and other plants, while in the opposite direction it dips 30 or 40 feet beneath the sea. The outer sides plunge, as usual, into deep water, while the inner descend gradually to 120 or 150 feet. Patches of coral are scattered over the lagoon, and adhere as fringing reefs to the steep islands rising out of it. On the larger island the coral reef rendered the water so shallow, that the larger boats could not come within 200 yards of the landing-place.

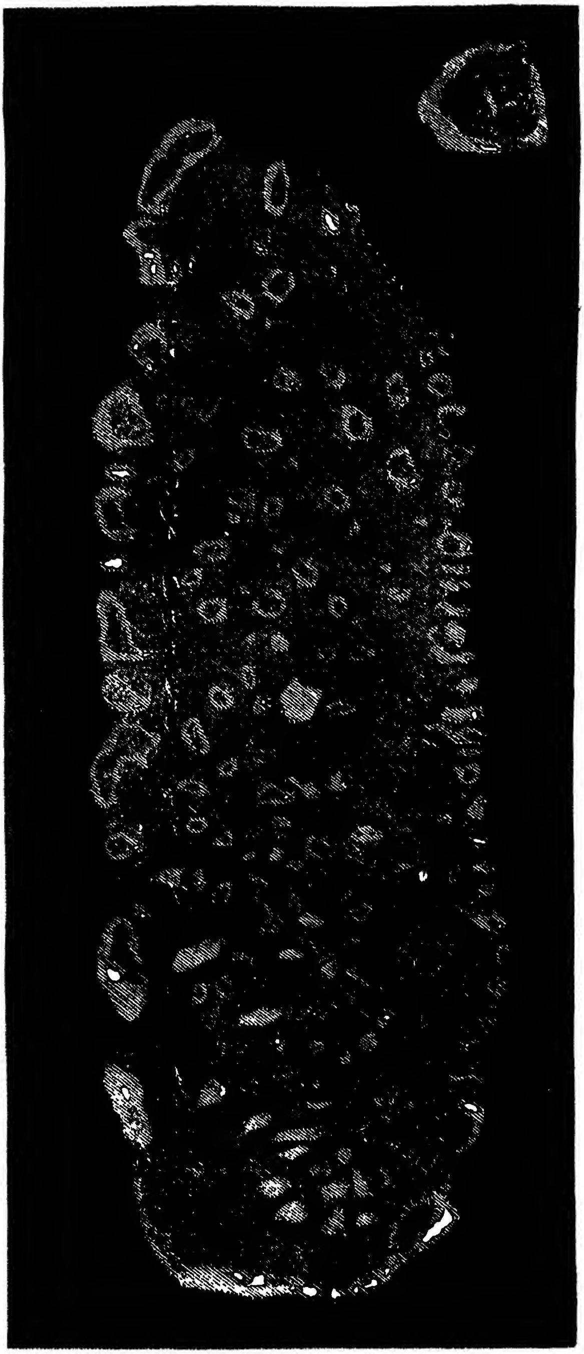
The annexed plan (fig. 75) of Ari Atoll, one of the Maldiva Islands,* exhibits a modification of those coral islands which have a general reef surrounding a lagoon. Here a number of reefs form an outer line, and the interior is occupied by a number of others. Many of these are ring-formed, so that the general group reminds us of many minor atolls, rising above an area of a tabular character, round which the sides plunge rapidly into deep water. The common depth between these reefs and islets, some rising above the level of the sea, varies from 150 to 200 feet, and in the basins of the ring-form detached reefs from 24 to 60 feet. According to Captain Moresby, the central and deepest part of the lagoons in the Maldiva Islands is formed of stiff clay, of sand near the border, and of hard sand-banks, sandstone, conglomerate, rubble, and a little live coral in the channels of the reef.† The other large islands, or rather groups of islets and reefs, of the Maldives, present the same general characters, while the smaller, one of which (Ross Atoll) is represented in the following page (fig. 75, *a*), offers the usual atoll character.

From the observations of Mr. Darwin on part of the coral reefs of the Mauritius, it would appear that the edge of the reef is formed of great masses of branching madrepores, chiefly *M. corymbosa* and *M. pocillifera*, mingled with a few other kinds of coral. To the depth of 48 feet, the coral ground appeared free from sand; but from that depth to 90 feet a little calcareous sand was brought up by the arming of the sounding-lead; more frequently, however, it came up clean. The two madrepores above mentioned, and two species of astræa, with large stars, seemed the commonest corals for the whole of this depth. Some fragments of *Millepora alcicornis* were brought up, and in the deeper parts were large beds of a seriatopora, allied to, but differing from, *S. subulata*. From

* Reduced from the chart of the Maldives, by Captain Moresby and Lieutenant Powell.

† As stated by Captain Moresby to Mr. Darwin. "Structure," &c., p. 34. Captain Moresby informed Mr. Darwin that *Millepora complanata* was one of the commonest kinds of corals on the outer margin of reefs of the Maldives. Ibid. p. 33.

Fig. 75.



a

90 to 120 feet the bottom, with few exceptions, was covered by sand, or strewed with seriatopora. From 120 to 198 feet, the soundings showed a sandy bottom, with one exception, at 180 feet, when the arming came up as if cut by the margin of a large caryophyllia. On the beach, the rolled fragments consisted chiefly of madrepores and astræa of the smaller depths, of a massive porites, like that at Keeling atoll, of a meandrina, *Pocillopora verrucosa*, and of numerous fragments of nullipora.*

The reef surrounding the Mauritius, excepting in two or three parts where the coast is almost precipitous,† generally ranges at a distance of one, two, or even three miles from the shore. Opposite every river and streamlet the reef is, as is common, breached, and the slope outside the reef seems generally to be moderate, bearing a relation to the slope of the adjoining land.

The Isle of Bourbon is also surrounded by coral reefs, only broken through at the embouchures of the rivers, and opposite the chief ravines. M. Siau, who had excellent opportunities of observing these reefs in 1839 and 1840, has stated‡ that the channels or passages through the reefs are kept open by the streams of fresh water passing outwards through them, and that they would be otherwise soon filled up. As it is, they are considered to have decreased in size, in consequence of a diminished quantity of rain having, of late years, fallen upon the Isle of Bourbon. These channels being, as usual in such situations, the passages to roadsteads behind the reefs, their condition is a constant subject of attention, and, as illustrative of the quick growth of certain at least of the reef-making corals of that locality, M. Siau mentions that, in one of the channels (that of the Rivière d'Abord), a coral rock has risen from the bottom, and in the middle of it, to the height of 29 feet (English) in 12 years. M. Siau§ presents us

* Darwin, "Structure of Coral Reefs." † Darwin, Ibid.

‡ Comptes Rendues, tom. xii., 1841.

§ M. Siau observes, that "the labours of the coral polyps are as varied as the species. Some (and these are the most widely spread) establish themselves by families at the bottom of the sea, on a volcanic or any other rock, unattackable by the action of the waves. Each family constructs a detached boss (*mamelon*) which may rise to the height of two or three yards by the labours of many generations. These bosses are known in the country by the name of *pâtés de coraux*. The bottom is thus covered by bosses, which most frequently join, touch, or approximate to each other, sometimes leaving open spaces between them, into which (coral) sand and shingle are washed by the sea. Such spaces are known as *rigoles de sables*.

"Upon this fresh bed new families establish themselves, constructing another bed. The latter are independent of the former. Sometimes they entirely repose

with a very interesting account of the mode of growth of the reef-making corals of this island, showing the establishment of a series of coral bosses upon each other, with the admixture of coral sand, and shingle, in the interstices between them, up to the level of the sea, where the labours of the reef-making coral polyps terminate.

---

on the first *pâtés*, sometimes on the *rigoles*, so as to conceal them; sometimes an isolated *pâté* completely covers a primitive *rigole*. The spaces between this second bed are also converted into *rigoles*, the sea throwing in sand and small shingles. Above this second bed other generations raise a fourth and a fifth, and thus the mass is formed of those immense reefs so common in intertropical seas.

"It would be wrong to conclude, from the description given, that the beds thus formed have a uniform thickness. It should be understood that very great differences exist in the height of the *pâtés*, and that the entire reef would present a shapeless and divided assemblage of superimposed montecules, the interstices between them filled with sand and shingles, their contiguous portions joined together by a coral cement.

"The corals of which we have spoken are the most common, forming the mass of the reefs. The coral produced is grey, very compact, of a very close grain, and often harder than marble. This coral is not worked away by the waves, and is not entirely soluble in acids. Upon the firm base of the bosses, above described, a variety of small and delicate corals, of different kinds, establish themselves. It is these fragile corals which alone furnish the white sand and shingles to the shore and the *rigoles*, and they are entirely soluble in acids."

The same author remarks upon the depths agitated by the waves, and infers (Comptes Rendues, tom. xii., p. 775) that he had evidence of that action at the depth of 578 French feet (616 English feet), on the north-west of the roadstead of St. Paul, Isle of Bourbon. It will be obvious that, in such researches, the friction on the bottom, by tidal streams, and ocean currents, has carefully to be distinguished from the movement produced among the particles of water beneath by the action of surface wind-friction waves above. Whatever the cause of motion in the superficial parts of the sea bottom, either from surface-wave action, or the friction of tidal streams, or ocean currents, the observation of M. Élie de Beaumont (appended to M. Siau's Paper), respecting an inquiry as to the depths at which *fixed* animals are found upon bottoms liable to this motion, such animals depending for their food upon the prey which may pass them, is equally important.

CHAPTER XI.

GREAT BARRIER REEF OF AUSTRALIA.—CORAL REEFS OF THE RED SEA.—CONDITIONS FOR THE OCCURRENCE OF CORAL REEFS.—INFLUENCE OF VOLCANIC ACTION ON CORAL REEFS.—COMPOSITION OF CORAL-REEF ACCUMULATIONS.—INFLUENCE OF CHANGES IN THE LEVEL OF SEA AND LAND.—REEFS NEAR BERMUDA.

THE Great Barrier Reef, extending off the east coast of Australia for about 1100 miles, with a mean breadth of about 30 miles, from Breaksea Spit, in lat. 24° 30′ S., and long. 153° 20′ E., to Bristow Island in lat. 9° 15′ S., and long. 143° 20′ E. off the coast of New Guinea, presents an area of about 33,000 square miles, chiefly covered with organic, mechanical, and chemical accumulations resulting from the secretions of the coral polyps. This great mass is broken northwards by the influence of river waters discharged from the south-eastern portion of New Guinea, carrying detritus with them, and covering the bottom of the adjacent seas with a muddy sediment. These conditions ceasing, we find the great coral accumulations continued to Louisiade, thus extending the surface, allowing for the great break above mentioned, over many more thousands of square miles.

The survey of Torres Straits, between Australia and New Guinea, by Captain Blackwood, has added materially to our knowledge of the Great Barrier Reef, and Mr. Beete Jukes, naturalist to the expedition, has afforded us very valuable information respecting it.* He divides the coral accumulation into—1st, linear reefs, forming the outer edge, or actual barrier; 2nd, detached reefs, lying outside the barrier; and 3rd, inner reefs, or those which lie between the barrier and the shore. With respect to the linear reefs, they are described as generally long and narrow, more or less parallel to the coast of Australia, and separated by narrow

* "Narrative of the Surveying Voyage of H.M.S. 'Fly' commanded by Captain Blackwood, R.N., in Torres Strait, New Guinea, &c." By J. Beete Jukes, M.A., &c. London, 1847.

breaks or passages, varying from 200 yards to a mile in width, and from half a mile to 15 miles in length. They have commonly great depths of water on the ocean side, lines of 100 or 200 fathoms rarely finding bottom close to the reefs, while the depths inside generally vary from 60 to 120 feet. The detached reefs occur only in one locality—somewhat in front of Cape Grenville, Australia (if we except the reefs eastward of the Great Barrier, eastward of Torres Strait), rise from deep water all round, and have more or less of a circular form, with lagoons inside. The inner reefs are very numerous, scattered over the platform beneath the more shallow water between the outer reefs and the coast of Australia, sometimes leaving an open channel between them and the land on the one side, or the barrier on the other. They are of different forms, have sometimes gradual slopes around, and at others are steep-sided.*

Mr. Beete Jukes observes, that up to about lat. 21° 10′, at Swain's Reefs, it can scarcely be said that any true barrier exists, there being merely a bank of soundings off the shore, "with large masses of coral reef settled upon it, and within its outer boundary,—almost equally large clear spaces intervening between the different groups of reefs. In Swain's Reefs, the individual reefs on the outer edge of the group can scarcely be distinguished in form from those inside them, although they may have a little more linear shape, and their greatest length runs more invariably along the line of the boundary of the group. It is only at their northern extremity that they assume one of the characteristics of a true barrier, that of rising like a wall from a deep and almost fathomless

* Beete Jukes, "Surveying Voyage of the 'Fly,'" vol. i., pp. 317–18. Mr. Beete Jukes gives a detailed account of the range of coral accumulations from Breaksea Spit (vol. i., pp. 318–332). Respecting the most southern portion, it is stated, that "from Sandy Cape (Australia), a sandy shoal runs out, partially covered by coral, as it proceeds outwards. It is formed of siliceous sand, with 10 or 20 fathoms of water upon it, sloping to 30 fathoms, after which it plunges into deep water. At the Capricorn Group, about 50 miles more northward, all—even the smallest grains of sand—was calcareous, and so it seemed to continue to the sedimentary matter brought down by the New Guinea rivers, eastward of Torres Strait.

"North of the parallel of 23° 10′, there is an open space of sea, in which no reefs occur, about 50 miles wide from north to south; and the bank of soundings instead of being a steep, well-defined edge, slopes out very gradually far to the eastward. The flat of about 20 fathoms, extends out as usual from the mainland for about 30 or 40 miles, and then gradually deepens, till 70, 80, 90, and 100 fathoms are successively attained, 20 or 30 miles eastward of the boundary of the line of soundings, as it exists to the southward. The character of the bottom likewise changes from a coarse coral to the finest possible mud, of a light olive-green colour, in which the lead often wholly buried itself on reaching the bottom. This, when dried, was also entirely calcareous, and wholly soluble in muriatic acid."—Ibid. vol. i., p. 320.

sea."* To the northward the reefs become more numerous. Where the detached reefs occur opposite Cape Grenville is a great bay in the barrier, with very deep water, a line of 1710 feet having failed to strike the bottom on it southern side, four miles inside the reefs forming the bay. Near this bay Yules' Detached Reef rises from an unknown depth, greater than 600 feet, and appears to have a lagoon in its centre. The Great Detached Reef rises on northward of this reef, also from a great depth, containing a lagoon with 180 feet of water in it.

Raine's Islet is also another detached reef rising with steep sides (in one place at an angle of 55°) from deep water. Bottom was found at 960 feet one mile north of the islet, and at 1080 feet two miles and a half north-east of it. On the southern side, bottom was not found until close to the breakers of the Great Barrier Reef, when fine coral sand was brought up from 1050 and 1200 feet.† Pandora's

* "Between Swain's Reefs and the mainland there is a space of 50 to 60 miles wide, clear of reefs, with a depth of 30 to 50 fathoms."—Beete Jukes, "Surveying Voyage of the 'Fly,'" vol. i., p. 321.

† Raine's Island is described as about 1000 yards long and 500 wide, rising in no part more than 20 feet above high-water mark. "It is formed of a plateau of calcareous sandstone, which has a little cliff all round, 4 or 5 feet high, outside of which is a belt of loose sand, forming a low ridge between it and the sea. Some mounds of loose sand also rest upon the stone, especially at its western end. The length of the island runs in about a N.N.W. and S.S.E. direction. It is surrounded by a coral reef, that is narrow on the lee side, but to windward, or towards the east, stretches out for nearly two miles. The surface of this reef is nearly all dry at low water, and its sides slope rapidly down to a depth of 150 or 200 fathoms." "The island is covered with a low scrubby vegetation," and "the central part of the island had a rich black soil several inches deep." The stone forming the base of the island is described as "made up of small round grains, some of them apparently rolled bits of coral and shell, but many of them evidently concretionary, having concentric coats. It was not unlike some varieties of oolite in texture and appearance. It contained large fragments of corals and shells and some pebbles of pumice, and it pielded occasionally a fine sand that was not calcareous, and which was probably derived from the pumice. Some parts of it made a fair building stone, but it got softer below, till it passed downwards into a coarse coral sand, unconsolidated, and falling to pieces on being touched. In the quarries opened next year for the beacon (constructed for the purposes of navigation), many recent shells, more or less perfect, were found compacted in the stone, and one or two nests of turtle's eggs, of which, in some cases, only the internal cast had been preserved, but in others the shell remained in the form of white carbonate of lime. Some drusy cavities were also found in the stone, containing crystals of gypsum." "It is evident from the fossil turtle eggs that the consolidation of the stone had taken place after it was raised above the sea. It was due, probably, to the infiltration of the rain-water percolating through the calcareous sand, that had been gradually piled above high-water mark by the combined action of the winds and the waves. The thickness of the vegetable soil in its centre shows that it has been above water for a great length of time."—Beete Jukes, "Voyage of the 'Fly,'" vol. i. pp. 126–128. The whole surface of the island was covered with birds—all but one kind, a land-rail—sea birds, such as frigate birds, boobies, gannets, &c. "On walking rapidly into the centre of the island, countless myriads of birds rose, shrieking on every side, so that the clangour was absolutely deafening, like the roar of some great cataract." There were turtle tracks on the beach, and the shells and skeletons of dead turtles were scattered about the island.

Entrance, through the Barrier Reef, occurs in 11° 10′ S., northward of the deep bay, and the detached reefs, after which the great reef is made up of long and closely-connected masses, with few and small gaps for 40 miles. From 10° 40′ to Flinders' Entrance, in lat. 9° 41′, the reefs consist of numerous spots and patches (too close to afford good entrance for vessels), forming submarine pinnacles or towers, rising from a depth of 90 or 120 feet, still, however, preserving the line of the barrier, with deep water outside, in which the bottom was not found with a line of 960 feet.

From Cape Weymouth and Restoration Island, in consequence of the altered run of the Australian coast and of the barrier reefs, the difference between the outer reef and the mainland in the parallel of Cape York (the N.E. point of Australia), has increased to 80 and 90 miles. The whole of the intermediate distance has not been surveyed, but Mr. Beete Jukes states, that there appear to be many inner reefs at a short distance from the land. Between these and the great eastern barrier, the sea is comparatively free from them, many sunken patches being, however, scattered about, and the bottom irregular in places. "The general depth varies from 12 to 20 fathoms, the bottom being coarse sand (with many foraminifera and detached corals and corallines), gradually passing as we approach the land into finer sand and detritus, and from that into the finest possible mud, wholly calcareous and lying close to the shore."*

The outer barrier terminates at Anchor Key, in lat. 9° 20′ S., and no coral reef is found further towards the coast of New Guinea, in this direction, except the Bramble Reef, described as fringed round other rocks. The chart shows coral sand and fragments on the bottom in 38 fathoms, increasing to 54 fathoms, and stretching out 50 miles to the eastward of the Bramble's Key, while all the soundings on the north, in front of a low coast, with a large discharge of fresh water from various channels in New Guinea, are of mud and sand. In front eastward of Flinders' Entrance, Portlock's reefs rise from a depth of 360 to 400 feet, so that on the north, as on the south, as is observed by Mr. Beete Jukes, the corals rise from the ocean in shallow water as compared with the central portions. Between Cape York and the opposite coast of New Guinea, extensive reefs seem to prevail adjoining the latter, rising out of 30 to 70 feet of water, and a considerable reef connects Warrior Island with the mainland of New Guinea. All the central parts of Torres Strait,

* Beete Jukes, "Voyage of the 'Fly,'" vol. i., p. 330.

from north to south, between Cape York and Turtle-Back Island, are remarkable for a nearly uniform bottom, 9 to 11 fathoms, formed of sand and mud. No coral reefs were found in this central band, except narrow fringing reefs round islands, formed of other materials,—porphyries, granites, and quartz rocks.*

Coral reefs are abundant in the Red Sea, fringing the coasts to a great extent. Numerous localities have been examined for a distance of about 200 miles by MM. Ehrenberg and Hemprich, and 150 species of corals were observed. According to the former,† these reefs form shallow incrustations on the rocks of the coasts, from 3 to 12 feet beneath the surface of the sea, often sloping outwards. They do not always adjoin the coast, but often form narrow parallel bands at various distances from it. The reefs are composed of Madrepora, Retepora, Millepora, Astræa, Favia, Caryophyllia, Mæandrina, Pocillopora and Stephanocora, mixed with

* Beete Jukes, ("Voyage of the 'Fly,'" vol. i., p. 331,) from his experience among the great coral accumulations of Eastern Australia, has given the following account of an individual coral reef.—"A submarine mound of rock, composed of the fragments and detritus of corals and shells, compacted together into a soft spongy stone. The greater part of the surface of this mound is quite flat and near the level of low water. At its edges it is commonly a little rounded off, or slopes gradually down to a depth of 2, 3, and 4 fathoms, and then pitches suddenly down with a very rapid slope into deep water, 20 or 200 fathoms, as the case may be. The surface of this reef, when exposed, looks like a great flat of sandstone with a few loose slabs lying about, or here and there an accumulation of dead broken coral branches, or a bank of dazzling white sand. It is, however, chequered with holes and hollows more or less deep, in which small living corals are growing; or has, perhaps, a large portion that is always covered by two or three feet of water at the lowest tides, and here are fields of corals, either clumps of branching Madrepores, or round stools and blocks of Mæandrina and Astræa, both dead and living. Proceeding from this central flat towards the edge, living corals become more and more abundant. As we get towards the windward side, we of course encounter the surf of breakers long before we can reach the extreme verge of the reef, and among these breakers we see immense blocks, often two or three yards (and sometimes much more), in diameter, lying loose upon the reef. These are sometimes within reach by a little wading; and though in some instances they are found to consist of several kinds of corals matted together, they are more often found to be large individual masses of species, which are either not found elsewhere and consequently never seen alive (Mr. Beete Jukes saw an irregular block of Mæandrina, of irregular shape, 12 to 15 feet in diameter), or which greatly surpass their brethren on other parts of the reef in size and importance. If we approach the lee edge of the reef, either by walking or in a boat, we find it covered with living corals, commonly Mæandrina, Astræa, and Madrepora, in about equal abundance, all glowing with rich colours, bristling with branches, or studded with great knobs and blocks. When the edge of the reef is very steep, it has sometimes overhanging ledges, and is generally indented by narrow winding channels and deep holes, leading into dark hollows and cavities where nothing can be seen. When the slope is more gentle, the great groups of living corals and intervening spaces of white sand can be still discerned through the clear water to a depth of 40 or 50 feet, beyond which the water recovers its usual deep blue. A coral reef, therefore, is a mass of brute matter living only at its outer surface, and chiefly on its lateral slopes."—Ibid. vol. i., pp. 314-316.

* "Uber die Natur und Bildung der Corallen-Bänken des Rothen Meeres," Berlin, 1834.

the shells of molluscs, the remains of fish, &c. According to M. Ehrenberg, the height, resulting from the accumulation of the same corals, is small. With respect to the banks and reefs lying some distance from the shore, Captain Moresby states that they appear more elongated than they really are when correct plans are constructed of them. Though many of these reefs rise to the surface, the greater number are found at depths from 30 to 180 feet, and consist of sand and living coral, the latter covering the largest part of their surfaces. They run parallel with the shore, sometimes connected with the mainland by transverse banks. Deep water occurs close to them.*

With respect to the varied conditions under which coral reefs are found, probably the observer may conveniently first consider the manner in which different species of coral have hitherto been known to occur. As Mr. Beete Jukes has remarked, though the reef-making coral polyps are only known to us as living at depths not extending beyond 120 to 180 feet, there may be others forming masses of calcareous matter at greater depths with which we are unacquainted.† The evidence respecting corals of various kinds would lead us to infer that, like the molluscs above mentioned (p. 146), while some prefer, or are adjusted to particular bottoms, whether solid rock, sand or mud, at various depths, moderate or considerable, others are only to be found in shallow water. Viewing the subject in this light, the corals living at the surface of the sea may be compared with littoral molluscs keeping situations peculiar to them. While some appear adjusted to the nearly constant movement of ocean breakers, others, even at small depths, require tranquil water; so that at nearly equal depths the corals, forming the hard mass of the reef, or finding shelter amid its cavities, in the lee of lagoons, when there are such, divide themselves into two classes.

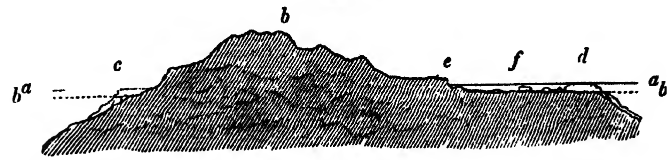
Referring to the early and swimming state of the reef-making coral polyps, we may assume that, wherever fitting conditions presented themselves, they could settle, adhere to a sufficiently hard substance, and commence the foundation of a reef. If we take coasts as they are variously presented to us, we find that, as regards depth, we may have the 120 or 180 feet, for the reef-making corals either close to the shore, or removed to various distances

* Darwin ("Structure and Distribution of Coral Reefs," p. 192), from information communicated to him by Captain Moresby.

† It would be well carefully to examine the coral reefs, which have been undoubtedly raised above the sea by geological movements, for the species contained in their lower parts.

from it. So that, assuming the swimming germs to meet with the requisite bottom, they can commence their reef-rearing labours at various distances from the land, and, raising the reefs, form very different lines around or adjoining it. Let, in the annexed diagram (fig. 76), *a a* be the surface of the sea round an island, *b b* the

Fig. 76.

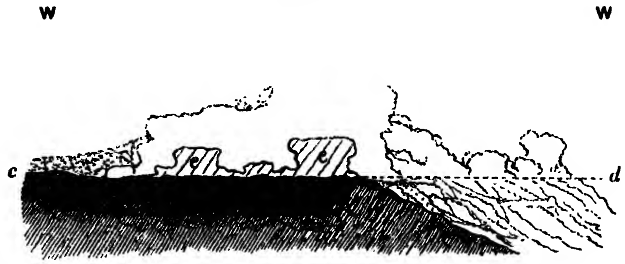


level beneath that surface at which the swimming coral germs can attach themselves and begin their labours, then at *c* the reef would be fringing and adjoining the coast; while at *d*, a bank might be raised up, forming a barrier reef to the coast *e*. Such a bank once established, the space *f*, between the coast, *e*, and the barrier, *d*, becomes fitted for those corals which require the shelter afforded by the latter. Whether from being best adapted for procuring food, or as affording conditions ill-suited to the coral-eating animals, the surface reef-making corals flourish in the surf of breakers, so that they grow, as a mass, outwards. With respect to original bottom, if there be sufficient tranquillity at the depth of 120 feet from wind-wave action, either directly produced on the spot by winds, or transmitted, as a ground or ocean-swell, from a distance, there appears no reason why the corals found at that depth, in lagoons and other sheltered situations inside barrier reefs, should not live and die under such circumstances, besides other corals, not yet known. These would form a base on which the more shallow water and littoral corals, among them those able to resist the breaker-surf itself, would begin their work. So long as these keep at sufficient depths, the mechanical action of the breakers will little affect them, but as they rise with the reef they gradually come within its influence, so that finally the coral masses are dealt with as the rocks of any other coast would be under similar conditions.

While corals thus forming a coast, may be, to a certain extent, adjusted to the powers of ordinary breakers, any increase in the force of the breakers over the resisting powers of the corals would break off portions of the latter, so that, during heavy gales of wind, the resistance becoming very unequal to the force employed, large masses of the coral are torn off and hurled over the reef inwards. This can scarcely happen without minor portions being also thrown over, or broken off from the detached masses, and the general

action such that fragments of the coral mass fall outside the steep slope of the outward growth, a steep slope which we should expect to have been gradually formed as the coral reef rose within the mechanical action of the breakers. Let *a b* (fig. 77) be the surface

Fig 77.



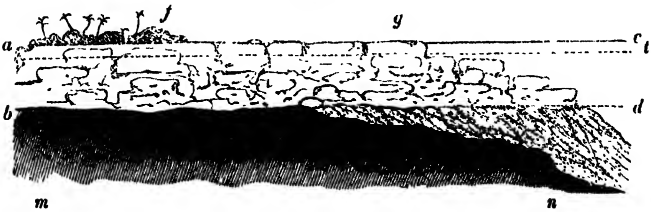
of the sea in calm weather (for the moment considered without reference to changes of level produced by tides), *c d*, a depth at which reef-making corals can, other conditions being favourable, establish themselves, and *e*, *e*, the commencement of a reef, not raised so high as materially to feel any of the mechanical effects arising from any wave action, W,W,W, though every successive addition to the reef would bring it more and more within that influence. When, by vertical increase in the coral mass, a breaker could be formed by sufficient proximity to the wave, W,W,W, abrasion would commence as the coral resistance became unequal to the force employed, and the detritus would be scattered on each side, the inside probably, from the direction in which the force was applied, receiving the chief portion, while some fell outwards towards *b d*. As the coral growth rose to the surface, under ordinary weather, the increase more than meeting the loss by abrasion, the interior would be filling up also by corals, some of which required the shelter there afforded them. Outside, the breaker action would remove the smaller fragments in mechanical suspension, leaving the larger blocks, so that hollows amid the latter would get filled with a portion of the finer matter, the greater part of which would be carried out at the base of the reef, more or less ground into sand by the friction to which it may have been exposed.

If we suppose the reef to have so risen that it touches the surface of the sea, the growth of the coral still increasing the mass beyond the power of the surf to break off portions of the reef, a time would come when, from the usual breaker action upon coasts previously mentioned, fragments of various sizes, with coral pebbles and sand, from continued friction of the fragments in the

surf, would be thrown up in a bank upon the reef, with [illegible] added by the winds. The decomposition of the animal matter in the more freshly broken pieces of coral, added to any animal matter entangled amid the reef, would assist in its consolidation by, among other things, the production of carbonic acid, for combination with the water to act on the carbonate of lime of the corals, so that sufficient would be taken up in solution to cement them together, by subsequent deposit among the coral fragments, thus forming conglomerates and sandstones. A dry portion once above water, the often-described vegetation succeeds, the decomposition of which also affords free carbonic acid for the further solution of carbonate of lime, and an additional consolidation of the mass beneath by chemical means. Considering the mixture of animal matter in the coral mass itself, entangled among it in various ways, and by its decomposition affording carbonic acid, and the conditions under which this carbonic acid could be brought to aid in the solution of the carbonate of lime of the coral polyps, it will be seen that circumstances may often arise for the obliteration of the organic texture, and the substitution of calcareous matter, presenting an inorganic character, such as has been often remarked.

The nearer the surface the greater would be the power of the breaker action to peel off the upper coating of the reef, during heavy gales of wind, and cast the fragments inwards as well as the rounded pebbles which may have been formed in fitting situations at ordinary times by the common force of the breakers. We should expect this to be effected to distances beyond the margin of the reef, dependant upon circumstances, among which the rise and fall of the tide, both during ordinary weather and at the time of any heavy gale of wind, have to be regarded. Assuming *c*, *t* (fig. 78) to be the difference of the tide level, it will be obvious

Fig. 78.



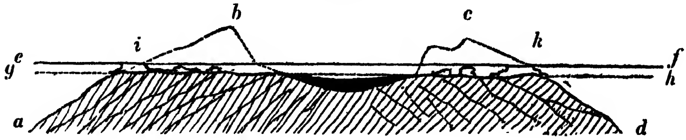
that any power which the breakers may have at the level *a*, *c*, will be changed during the rise and fall of the tide, ranging up and down all the portions of the reef exposed within the depth *t*, *c*. We have assumed as in the accompanying section (fig. 77),

that the coral animals in their free swimming state met with a bank *m*, *n*, so that at the level *b*, *d*, they found the conditions, as to depth and other things suited to them. Assuming that they would not work beneath this level, as the reef rose to the island *f*, *g*, and the detritus outside accumulated, the latter would cover over the deeper part *n*, of the original bank, by successive coatings, over which the coral polyps would advance their work laterally, thus covering horizontally a detrital mass, laminated at an angle according to the slope on which it may accumulate. Taking the outside detrital increase at any given amount of cubic contents, it would follow that, according to the small slope of the original bank would be the rapidity of the lateral advance over which the corals might be disposed to work, steep slopes affording the least ground at a given level for such increase. For the sake of easy illustration we have assumed a bank such as that near Breaksea Spit, on the coast of Australia, and above mentioned (p. 182), which after retaining a certain general depth, and presenting a rounded margin, plunges into deep water.

It may now be desirable to consider the effects which would result, in the regions of coral reefs, from volcanic action. We have seen that within our own times, volcanic action has brought ashes and cinders to, and above the sea level in the Mediterranean (p. 70) and in the Atlantic (p. 100), that the islands so produced have been temporary, and that very probably the incoherent matter of which they were composed has been cut down to the depths at which breaker, or wave action could disturb and remove such matter. At least this could scarcely but happen, supposing no subsidence from the pressure of the water into the crater in such a manner as to lower the volcanic mass, independently of any subsidence from volcanic causes themselves, carrying down the mass of ashes and cinders beyond the influences of breakers and waves.

If in the annexed diagram (fig. 79) we consider *a*, *b*, *c*, *d*, to

Fig 79.

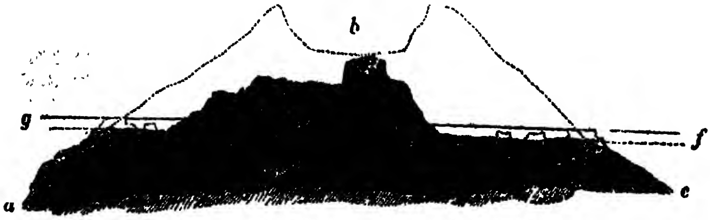


be a section of a volcanic cone, the top of which was forced during some eruption above the level of the sea, *e*, *f*, that this condition ceasing, breaker and wave action cut down the loose materials to the level *g*, *h*, one to which their influence could extend, even

probably sifting the ashes and cinders, as in the case of the Island of Sciacca (Mediterranean), so that a somewhat stony bottom might be the result, we should have conditions fitted, in the coral-reef seas, for the settlement of the germs of the reef-making polyps at *i* and *k*. At those points of the section the reefs would increase as above noticed, when they rose sufficiently high to be acted upon by the breakers, fragments broken off, and partly thrown down on the outsides, towards *a* and *d*, and the corals spreading over them as previously noticed. Inside there would be a lagoon, which, as soon as a general barrier of coral was established outside, would be filled in the usual manner with corals and other marine creatures suited to the sheltered conditions there found. The overflow of the breaker-waters, and the rise and fall of tides combined, would tend to keep open a channel or channels between the lagoon and the sea outside, and finally, terrestrial vegetation would establish itself upon a coral bank chiefly raised into the atmosphere by the piling influence of the breakers upon the coral ridge. The forms of such islands would necessarily depend much on the horizontal section of the volcanic accumulation, when cut down by breaker and wave action. We should expect the submarine and steep flanks of the mass to be encrusted by coral sands and fragments in proportion to the time during which the reef-corals may have been increasing outwards in any particular locality, so that the sounding-lead could bring up little else around the coral reefs and island except coral detritus, and the marine animals which could exist under the needful conditions at various depths around the main mass.

As we have abundant proofs that, not only ashes and cinders have been vomited out of volcanic vents, reaching to and beyond the sea-level, but molten rock also, the whole even attaining considerable altitudes, such as the volcanic heights of Hawaii, and others of the Sandwich Islands, with deep water around them, it may not be undesirable to consider the conditions under which coral reefs might be gathered around such volcanic masses. Let, in the annexed section (fig. 80) *a*, *b*, *c*, represent the remains of a mixed volcanic mass of molten rock, and of ashes and cinders, cut away by atmospheric influences and breaker action, so that a portion of hard rock, *b*, perhaps once molten matter in the crater of a volcano, stands above the level of the sea, while at *g* and *f* incoherent ashes and cinders are cut back by breaker action (as in fig. 79) to this hard rock. We should now have conditions for the formation of reefs at *f* and *g* under the same circumstances as above noticed (fig. 79),

Fig. 80.



with this difference, that instead of an uninterrupted lagoon in the interior of the coral reefs, there would be land emerging from it, so that these reefs would be encircling. In addition to the usual causes of keeping channels open, the islands, if of good size, might contribute fresh-water streams, at times charged with detrital matter, preventing the increase of the coral reefs in the lines which they traversed.

It would appear desirable, in the first instance, that an observer should direct his attention to the conditions under which coral reefs and islands could be formed, either as lagoon islands, reefs touching or encircling land composed of ordinary detrital or igneous rocks, or upon shoals and banks ranging in front of considerable lines of coast. It is not a little interesting further to consider the mode in which a general mass of coral matter would be composed, after a lapse of time sufficient to complete the filling up of lagoons, with or without the protrusion of dry land formed of ordinary rocks through them, or the space between an outer line of coral reefs and a considerable range of coast, such as that of a portion of Eastern Australia.

As to the height to which corals may rise, Mr. Beete Jukes found coral polyps alive six or eight inches out of water, and so remaining for nearly an hour, until the return of the tide. He often observed the same fact, and believes that an exposure to the air and sun will not kill many of the polyps, so long as the coral remains in a position of growth, the cells retaining their moisture. He has seen blocks of living astræa, the tops of which were 18 inches above water. This shows that we may take the ordinary tide level for that to which the reef-making coral polyps can work under favourable conditions; and that there may be a mass of matter coinciding with the line of a main reef round a lagoon-encircling island, or in front of a long range of coast, which may, from the top to the other substances on which the reef reposes, be chiefly formed by the growth of corals upon each other, occasionally mixed with the hard remains of marine animals inhabiting the cavities amid the corals, and with detrital portions driven in amid the hollows of the rising mass.

To whatever extent the germs of coral polyps could settle upon any surface, beneath the sea-level, suited to their development, conditions would change, as the reef portion rose seaward, behind the shelter gradually afforded from the roll of the waves, and their action on the bottom beneath; so that while sands and fragments of corals, broken off by the breakers, arranged themselves, as above mentioned, outwards, (the reef-making polyps working over this detritus,) a very complicated series of deposits and coral growths would be formed inwards. In the case of coral lagoon-islands, there would finally be calcareous plateaux of very variable areas, some many square miles in extent, of equal levels, separated, in such regions as the coral island groups of the Pacific Ocean, by irregular intervals of deep water. These isolated sheets of matter of general similar character would be, to a certain extent, stratified, though coral growths may pierce the general mass in various directions; the strata composed of beds of coral sand and mud, as these gradually accumulated, mingled with the shells of molluscs, the spines and coverings of echinoderms, the hard remains of fish, with possibly also those of certain birds and turtles, even the eggs of the latter being preserved in the higher sand-banks. There would be deposits of calcareous mud outside also, at depths where it could accumulate in an undisturbed manner; this calcareous mud borne out of the outlet channels during ebb-tides, and when heavy gales drove an abundance of water over the weather-side of the encircling reefs, to escape out of the same channels. Such mud might be widely spread by tidal streams and ocean currents, and so far constitute a kind of connexion, enveloping uneven and submarine ground, between the coral plateaux.

In the case of the reefs, more or less encircling islands of varied magnitudes, and composed of ordinary sedimentary and igneous rocks, there would be a modification of the deposits inside the reefs, so far as a supply of decomposed mineral matter from atmospheric influences and ordinary detritus from such lands would be concerned. The remains of a larger and more varied amount of terrestrial vegetable and animal life would be there expected; as, also, under favourable conditions, the addition of the harder parts of fluviatile creatures. Where intermingled with the simple lagoon reefs, there would be corresponding modifications of the interior deposits at the same general level.

As respects the accumulations, for so many thousand square miles, inside the Great Barrier Reef, off the eastern coast of Australia, there would be a great sheet of matter, as a whole,

having a certain general character. Viewing, generally, this range of coast, there is a great absence of fresh waters draining from the adjoining land; indeed, water is scarce along it under ordinary conditions. Hence no material influence is exercised on the growth of the coral polyps, and their associated life, by rivers and streams of fresh water, either clear or charged with detritus in mechanical suspension. Seaward we have the same conditions as the outward portions of the lagoon reefs, for about 1000 miles; the southern portion ranging beyond the circumstances fitted for the development of the reef-making coral germs, and resting on banks of ordinary silicious sand, while the northern portion is terminated by the influx of river waters, bringing down muddy matter from New Guinea; thus also preventing the same germs from properly establishing themselves, though conditions would otherwise appear to be fitted for their development, for passing the outflow of the river waters, coral reefs are again established to the northward.

Inside this long line of outer reefs, accumulations are effected as in the ordinary isolated lagoon reefs, until the main line of coast is approached, where modifications would be expected, though on a larger scale, of the kind found around the islands, composed of ordinary rocks, inside encircling reefs, and above noticed.* Such a small volume of fresh waters flowing outwards from the land, comparatively little detrital matter from the interior seems transported far seaward, so that the calcareous detritus derived directly from the reefs, and ground finer by friction from breaker action, or passed through the animals feeding on the coral polyps, readily becomes forced towards the land from the prevalent action of the waves in that direction. It there mingles near the coasts with such detritus as may be derived from the land by breakers, however modified these may be from the shelter afforded by the outer reefs, or be carried out into such tidal streams as prevail by the rivers in flood. Viewed as a whole, we should expect much continuity in some of the deposits, particularly the finest, in many parts of the great area comprised between the coasts and the outer great barrier reefs, in which an abundance of molluscs, radiata, and layers of certain corals, with the harder parts of fish and crustaceans, would be entombed. Near the land, and particularly where mangrove swamps prevail, there would be modifications of these continuous deposits. As a whole, it would constitute a great mass

* The green mud off Cape Direction, east coast of Australia, is wholly calcareous. —Beete Jukes, "Narrative," &c.

more or less stratified, intermingled here and there, especially towards the outer barrier reefs, with complicated mixtures of coral growth in reefs, the detrital matter derived from them, the harder parts of other marine animals living among them, and the alterations of structure produced by chemical means.

Stratification, or an approximation to it, is not confined to the coral sands and mud, and the layers of organic remains which may be intermingled with them, for a tendency to split into slabs is often noticed in the mass of the reefs. Indeed, Mr. Beete Jukes not only mentions such a mode of occurrence at Heron Island (part of the eastern Australian coral accumulation), but joints in that reef also, splitting the coral rock into blocks of from one foot to two feet in the sides. These joints or divisional planes are parallel to the dip and range of the beds respectively, and the coral beds dip seaward at an angle of from 8° to 10°.

The observer has next to turn his attention to the consequences, as regards coral reefs and islands, which would follow any of those changes of the relative levels of sea and land, both on the small and large scale, and to be subsequently further noticed, which the study of geology teaches us has so frequently occurred.

There can be little doubt of coral banks and reefs similar to those in the seas of our times, and in coral-reef regions, having been raised above the surface of the sea, like other marine accumulations, forming dry land. Such have been long known. MM. Quoy and Gaimard, who accompanied the expedition of M. Freycinet, and who remarked on the moderate depths to which the reef-making corals appeared to extend,* mention that on the coasts of Timor coral banks so occur above the sea level as to have induced M. Peron to consider the whole land formed of them.† At Oahu, and other places in the Sandwich Islands, coral banks have been long known to extend inland, and more modern researches have confirmed these observations. Mr. Couthouy, in particular, gives an account of ancient reefs, now raised above the sea level, at the islands of Maui, Morokai, Oahu, and Tauai.‡ We had occasion to remark also some years since on the raised coral reefs on part of the coast of Jamaica.§ Elizabeth Island, off the eastern side of the low archipelago,

* Quoy and Gaimard, Sur l'Accroisement des Polypes Lithophytes considéré géologiquement, Annales des Sciences Naturelles, tom. vi.

† Upon proceeding inland a short distance, MM. Quoy and Gaimard found these coral banks resting on vertical beds of slate.

‡ Remarks on Coral Formations.

§ Geological Manual, 3rd edit. 1833, p. 165.

(between Ducie and Pitcairn Islands,) has been considered, from the description of Captain Beechey,* to be a good case of a raised coral island, its flat summit 80 feet above the sea. Mr. Darwin has accumulated a mass of information† from the personal communications of the Rev. J. Williams, Mr. Martens, (of Sydney,) and Mr. G. Bennett, and from numerous voyagers, and other authors, showing coral banks elevated to various heights above the level of the sea in the Cook and Austral Islands, Savage Islands, the Friendly Islands, the Navigator Group, the New Hebrides, New Ireland, the Marianas, the East India Archipelago, the Loo-Choo Islands, Ceylon, Mauritius, Madagascar, part of the eastern coast of Africa, the Red Sea, and the West India Archipelago. In fact, this list comprises examples in all seas where coral reefs and islands have been noticed, and leaves little doubt that since coral reefs and islands were formed, as they now are, in the fitting regions, many throughout those regions have been raised above the level of the sea into the atmosphere.

Lafû Island, one of the Loyalty group, has also been noticed by the Rev. W. B. Clarke as a raised coral island. It is about 90 miles in circumference, and surrounded by a fringing reef, upon which the depth gradually increases outwards for a quarter of a mile, the reef then plunging into deep water. The whole island is composed of dead coral. Its average height above the sea is about 120 feet; and it attains, at points on the eastern side, an elevation of 250 feet. There is a ledge or shelf, like that now surrounding the island, at 70 or 80 feet above the sea. The surface is table land, with hollows and elevations, such as characterise a coral reef. Mr. Clarke infers that this island has been elevated at two distinct periods; at the first to the amount of 170 feet, at the second to 80 feet additional height.‡

In considering the elevation of coral reefs above the sea-level, the portions of a sea-bottom should also be taken into account, which may by the same means be brought within such a distance of the surface water, that the germs of the various coral polyps, which aid in the establishment of a reef, could find the needful conditions for establishing themselves. It has to be borne in mind that inequalities of the sea-bottom exist as much in coral regions

* Beechey, Voyage to the Pacific.

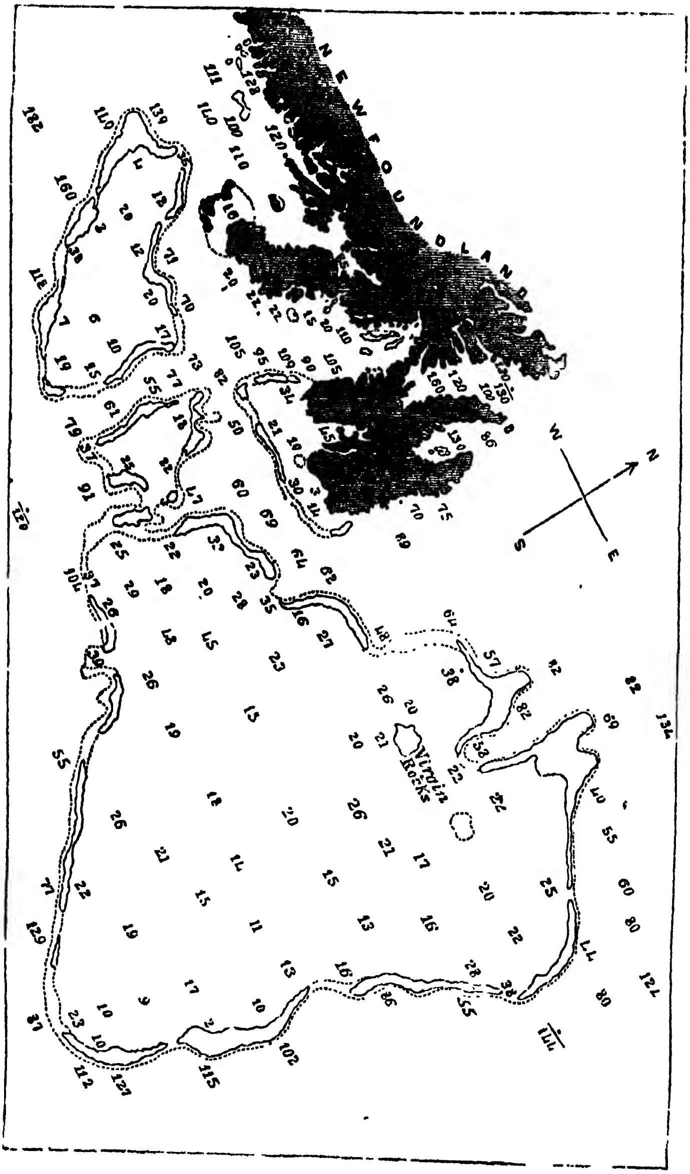
† Darwin, Structure and Distribution of Coral Reefs, pp. 132-137.

‡ Clarke, Quarterly Journal of the Geological Society of London, vol. iii., p. 61, 1847.

as in others; indeed, the igneous character of many islands, parti-cularly in the Oceans, would lead us to expect no slight variations in this respect. Many a boss or extended collection of volcanic inequalities may be raised by the same movements as those which have elevated the coral banks to various altitudes above the sea. While some pierced the surface-level of the water, to be dealt with by the atmosphere and the breakers, as far as their varied resistances to the destructive action of the one or the other might permit, others would be differently circumstanced. Some formed of incoherent cinders and ashes would readily be cut down to the level to which breaker action could extend; while others would only just reach the needful depth beneath the surface-water for the establishment of coral reefs.

As respects inequalities of sea-bottom, if the Great Bank of Newfoundland were in coral regions, and were elevated from its present relative level, so that its broad platform with its common depth of from 40 to 50 fathoms, one small portion of the area being occupied by the Virgin Rocks, were raised about 20 fathoms, by which coral reef-making germs could fix and develop themselves under fitting conditions, we should have an area of between 35,000 to 40,000 square miles, around the irregular margin of which there would be conditions, as represented in fig. 81 (p. 198), for an extended border of coral reefs. The sea around the margin would often be suddenly deep. The new Admiralty Chart of the North Atlantic gives 106, 137, 147, 132, 107, and 149 fathoms, as now found close off the south-eastern side of the Great Bank. There would be an island of small size, now the Virgin Rocks, above water with still 20 fathoms close to it; and supposing a somewhat questionable shoal (with 3½ fathoms upon it), about 40 miles to the eastward of the Virgin Rocks to be really existing, there would be another small island in the same area. The Great Bank, with its continuation the Green Bank, would be separated by a channel, then 55 to 79 fathoms deep, from the St. Pierre Bank, round the edges of which there would be conditions for a fringe of coral reefs, enclosing a large area of water with no other land above its surface. Indeed, the St. Pierre Bank would then bear an external resemblance to a great atoll, about 140 miles across from south-east to north-west, with a maximum breadth from south-west to north-east of about 70 miles, and having a somewhat steep slope

Fig. 81.



outside, on the south-west side, into 118, 160, and 149 fathoms, the change from the present depths being taken into account.*

In the Bermudas we seem to have an instance of an isolated bank in the Atlantic, far distant from land, and rising from deep water, upon the upper part of the crown of which coral reefs have established themselves, mingled with others which have been described as chiefly composed of serpulæ, nulliporæ incrusting the work of the marine animals as upon the coral reefs of the Pacific (p. 169).† The remarks of Captain Nelson, of the Royal Engineers, having chiefly reference to the geological structure of these islands, there is yet much to be accomplished by the experienced naturalist respecting the reefs themselves, which are especially interesting from their geographical position, and the marine life connected with it.

Although deep water is reported to surround the bank upon which the reefs and isles of Bermuda are situated, the reefs themselves are immediately bounded outwards by shallow water, only 6 and 7 fathoms being marked on the charts as a somewhat common depth immediately beyond the reef, deepening somewhat further distant to 12 and 15 fathoms. Captain Nelson describes ‡ the Bermudan group to consist of about 150 islets, lying in a north-east and south-west direction, within a space of 15 by 5 miles, and containing altogether an area of about 21 square miles. This group is situated very near, and conformably to, the south-east side of a belt of reefs, partly formed by corals, and partly by serpulæ, of a rude elliptical form, 25 miles long by 13 miles broad.

* The extensive submarine area of the Newfoundland banks is also highly interesting, as exhibiting a very slight difference in level. From 250 to 300 feet beneath the surface-water seems a very common depth, though there appear to be gradual swelling portions bringing the bottom more upwards. If these banks were elevated above the sea, they would present an irregularly bounded platform, divided by one main channel, many thousand square miles in extent, the chief height above which would be a rocky eminence, about 240 feet above the general surface, where the Virgin Rocks now occur; and, if the questionable shoal on the eastward really exists, a boss of ground of about the same altitude in that direction also. If these banks have been in previous geological times raised into the atmosphere, all traces of considerable hills and valleys, which may then have existed, have been obliterated. And this may readily have happened from the levelling effects of breaker action, combined with the distribution of the detritus by tidal streams and ocean currents, as the land may have slowly subsided. Be this as it may, detritus would not readily be now borne to these banks from the adjoining coasts of Newfoundland by any drifting action along the bottom, since, as previously mentioned, deep water occurs between the banks and that land.

† The occurrence of coral reefs so far northward in the Atlantic is referred to the influence of the heated water carried northerly by the Gulf Stream.

‡ Nelson, Transactions of the Geological Society of London, 2nd series, vol. v.

The channels amid the islets are shallow, and the depth of water within the boundary reefs rarely exceeds 12 to 14 fathoms. The highest land rises to about 260 feet above the sea at Sears Hill, and Gibbs Hill has an elevation of 245 feet.

Captain Nelson describes the islands as altogether calcareous, the beds varying from loose sand to limestone, so compact as to receive a good polish, the whole derived from animal secretions, chiefly marine, though the remains of land shells, and birds' bones are also mentioned. From the mode of occurrence of the calcareous beds, and especially from the saddle-shaped sections observable throughout the islets, Captain Nelson infers that the deposits have been effected by means of the wind, driving the calcareous sands, including fragments of, and whole shells, in the usual way before it, and heaping them up irregularly into sand-hills, the component parts of which have been variously consolidated. A foot of red earth, containing vegetable matter, commonly covers the calcareous accumulations. Fragments of coral and shells are noticed as common, and the remains of *Lucina* (*Venus*) *Pennsylvanica* are especially pointed at as frequent. *Turbo Pica* is also common; and Captain Nelson is inclined to refer its occurrence on the heights to the hermit crabs, which he has seen running about with these shells.* Coral reefs occur inside the main, or outside reefs, and do not rise above low water, except at spring tides. Over the bottom of this basin calcareous sand and chalky clay (the best anchoring ground) are distributed. The tides average a rise and fall of about 4½ feet, and at low water the main reefs stand about 2 feet above the sea.

Although there may be good evidence of much of the calcareous accumulations of these islets having been effected by means of the wind, piling up sand and fine calcareous particles driven, in the usual way, by breaker action at high tides, and by gales of wind,† still there would also appear evidence that there may have been some elevation of the general mass, since a bed containing shells of the *Lucina Pennsylvanica*, and now about 6 feet above water, has an even range from Phyllis Island to Harris Island. Under this

* *Mellita* (*Scutella*) *quinquefora* is noticed as found, the pores of the crusts filled with crystalline carbonate of lime, like the echinites in the European chalk. Turtles' bones have been discovered in the accumulations, as also the remains of cypræa and bulla.

† Sand drifts are now in progress; and Captain Nelson especially refers to one encroaching on the land, and arising from works executed a few years since, by which a protecting vegetation was removed, and the wind acted on a sufficient area of free sand to work its destructive way into a more considerable mass.

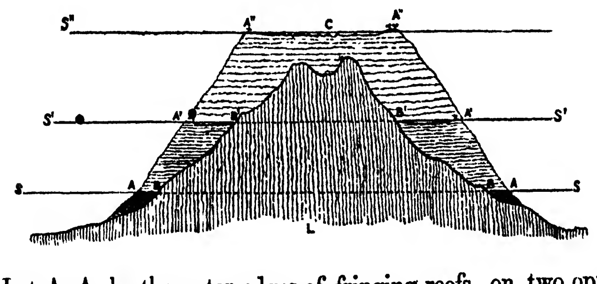
hypothesis a mixed accumulation, by means of both wind and water, would not appear inconsistent with the sections given by Captain Nelson. The following (fig. 82) is one similar to many sections of sandstone deposits formed beneath water.

Fig. 82.

a, b, c, Ordinary friable calcareous rock.
d, Recent loose deposit in front of the cliff.

Having so much evidence of the elevation of coral reefs in various parts of the world, and seeing that depressions of ordinary rock-accumulations (to be hereafter noticed) have been effected, often on the large scale, also in various regions, it would be expected that coral reefs, and even extended areas in which they occur, may in like manner have been subjected to the like movements. Mr. Darwin has very ably sustained this view, both as respects single coral reefs, and extended regions in which they may be found.* To account for barrier reefs and atolls, which have been produced by the subsidence of land, around which fringing coral reefs only were first attached, he gives the following illustration:—†

Fig. 83.



Let A, A, be the outer edges of fringing reefs, on two opposite sides of an island L, at a sea-level, S, S; B, B, shores of the island; A', A', outer edges of the fringing reef, after its upper growth, during the gradual subsidence of the island L, by which the relative sea-level became transferred to S', S'; then A' B',

* Darwin, Structure and Distribution of Coral Reefs, chap. vi. On the distribution of coral reefs with reference to the theory of their formation.

† In this section the two diagrams given by Mr. Darwin (Structure of Coral Reefs, pp. 98 and 100), have, for convenience, been thrown into one, in other respects they are the same. As Mr. Darwin points out, the sections of the lagoons are exaggerated.

B′ A′, are sections of the lagoons inside barrier reefs on each side of the land, after this subsidence, and B′ B′ the new shores of the island. Should the gradual subsidence continue, so that the relative level of the sea, as regards the island L, be changed to S″ S″, then the original island round which the corals first formed a fringing belt, would be completely concealed, A″ A″ constituting the outer reefs of an atoll, and C its contained lagoon. In this manner the original mass of land, which might be a volcanic cone, or some modification of that form, would become encrusted by the remains of marine animals, or the detrital and chemical accumulations arising from such remains, including the fæces of the various reptiles, fish, crustaceans, molluscs, and other marine creatures which inhabited the reefs and lagoons. This would be contained within a general crust, due chiefly to the work of the outer reef-making polyps; this crust again covered, after a certain depth, by the débris of the reefs, broken away by breaker action, as the subsidence continued, and accumulated over the first formed reefs in the usual talus. With the exception of certain portions of this outside distribution of the débris from breaker action, there would be a general horizontal arrangement of the rest; even the crust of the outer reef exhibiting, to a certain extent, this mode of accumulation. A large volume of calcareous matter, obtained by marine animals from the sea and their food, mingled with some terrestrial vegetable and animal matter, would be thus accumulated;—and no small amount would be required to fill in, as it were, the space between the outer crust of the rising reefs and the original land.

Assuming the hypothesis good for the single case adduced, there would appear no difficulty in applying it to a variety of modifications, arising either from the form of the original land, which may be either of small or considerable extent, mountainous or hilly in one part, and more level at others; or from the altered and changing arrangements of the surface distribution of land and water, at different times as the subsidence continued, being more sudden at one time than at another, or being interrupted by pauses of greater or less duration.* The Maldives are considered as affording a good example of the effects of the submergence of the land, after the first incrustation of its shores by the reef-making corals, so that a considerable fringing reef round a large island, like that of New Caledonia, became divided up into numerous rings of coral

* The varied effects of submergence of coral reefs and islands will be found treated at length, and with reference to reefs and islands considered to bear out this view, in Mr. Darwin's Structure of Coral Reefs, chapter v., entitled Theory of the Formation of the different Classes of Coral Reefs.

reefs, crowning different heights of the original land, the general outline of the latter still preserved from the upward increase the general mass of the corals. The Great Chagos Bank, on the south of the Maldives, presents peculiarities well worthy of attention;* and Mr. Darwin considers it as an instance, in which the corals of the main reef perished before or during a submergence, now such that the great outer reef, instead of being within the break of the sea, is sunk from 5 to 10 fathoms beneath the surface of the water, two or three spots only rising into islets. As the depth of the outer reef does not appear such as to prevent reef-making corals from developing themselves, and as interior knolls present themselves at the same depth with luxuriantly-growing corals, there would appear some other reason than mere depth of water, with its consequences, preventing the establishment of more than a slight amount of living coral polyps on these reefs. Supposing the outer reef to have once flourished in the common manner, at and near the surface (and there are still two or three islets above water), perhaps the somewhat sudden submergence of an extended range of islets, thickly studded over the outer reef, with their vegetation and sands, would, for a long time at least, be very unfavourable to conditions well suited for the re-establishment of the upper reef-making corals. Wave and tidal action would tend to distribute and move about the sands over the sunk reef in a manner scarcely fitted to the habits of the upper reef-making coral polyps, or the firm establishment of their germs.

With regard to the incrusting of islands by coral masses, including the accumulations mechanically and chemically obtained from the stony matter, chiefly calcareous, secreted by the

* "The longest axis is ninety nautical miles, and another line drawn at right angles to the first, across the broadest part, is seventy. The central part consists of a level, muddy flat, between forty and fifty fathoms deep, which is surrounded on all sides, with the exception of some breaches, by the steep edges of a set of banks, rudely arranged in a circle. These banks consist of sand, with a very little live coral; they vary in breadth from five to twelve miles, and on an average lie about sixteen fathoms beneath the surface; they are bordered by the steep edges of a third narrow and upper bank, which forms the rim of the whole. The rim is about a mile in width, and with the exception of two or three spots where islets have been formed, is submerged between five and ten fathoms. It consists of smooth, hard rock, covered with a thin layer of sand, but with scarcely any live coral; it is steep on both sides, and outwards slopes abruptly into unfathomable depths. At a distance of less than half a mile from one part, no bottom was found with 190 fathoms; and off another point, at a somewhat greater distance, there was none with 210 fathoms. Small steep-sided banks or knolls, covered with luxuriantly-growing coral, rise from the interior expanse to the same level with the external rim, which, as we have seen, is formed only of dead rock."—Darwin, Structure and Distribution of Coral Reefs, p. 39.

polyps and other marine creatures forming or inhabiting coral reefs, if we can have a growth and accumulation adjusted to the submergence,* the geological results would be such that upon again being elevated above the sea-level, (as has happened so often with many regions during the lapse of geological time after submergence), in areas such as that of the corallian portions of the Pacific, numerous masses of calcareous accumulations would present themselves, often, perhaps, corresponding in general character at equal, or nearly equal levels, and having the appearance of being the remains of limestone deposits, once continuous, though in reality they had never been united. If the Cape de Verde Islands, the Canaries, and the Azores, were to be incrusted with coral reefs, and be gradually depressed beneath the level of the sea, so that the reefs and the consequent accumulations inwards could be adjusted to the rate of submergence, and were again raised above the sea (as at least some of them would appear to have been, since notwithstanding their general igneous character, sea-bottoms and shores around them, of the more recent geological times, termed the tertiary, are uplifted), these fallacious appearances would be very marked.†

The observer would readily expect to find, in regions where coral reefs abound, and volcanos are now, or have been active during their formation, that there are occasional mixtures of igneous products with the coral accumulations. In Mr. Beete Jukes' account of the Great Barrier Reefs of Australia, he mentions mingled substances of this kind at Murray and Erroob

---

* If the submergence were so rapid that the growth, and consequent accumulations inside the reefs did not become adjusted to it, and supposing the reef-making corals only able to flourish in certain minor depths, it is obvious that the reefs could not increase upwards, but remain beneath like any mass of inorganic matter, the reef-making polyps perishing.

With respect to the rate of growth of reef-making corals, the evidence is at present somewhat uncertain and contradictory. Some contend that the growth is very slight, reefs having been known in their present state for a long time; while others consider their increase as more rapid. There is evidently a want of more information on this subject, especially as respects the conditions under which the appearances supporting these different views may have been caused.

† There are suddenly very considerable depths around the Cape de Verde Islands. Even in the channel between Sal and Bonavista, a line of 232 fathoms found no bottom. The same with the Canaries. There is no bottom at 309 fathoms close on the north of Palma. The like with Madeira, off the west end of which a line of 280 fathoms does not reach the bottom. Very deep water surrounds the various islands of the Azores. There is a depth of 300 fathoms close on the south of Santa Maria, and no bottom with 320 fathoms of line between that island and the Formigas, on the north-east. Around Pico, Fayal, San Jorgo, and Terceira, there are depths of 200 and 300 fathoms near the land; and there is very deep water around Flores, the most western isle.

Islands, where beds are found containing variable portions of trachytic lava and calcareous rocks, some of the lumps of lava and limestone being apparently rounded by attrition. There are also beds of volcanic ash, or sand, in which calcareous grains are dispersed. In Erroob, igneous rocks cover the sandstones and conglomerates. In this region, also, pumice would appear to have been at one time much drifted about, arising probably from volcanic eruptions in directions whence a portion of this light substance could be driven by prevalent winds and currents. It seems to have become mingled with the coral deposits. Portions of it are embedded in the coral rock of Raine's Islet, and are frequent in the coral conglomerate on the north-east coast of Australia.* Captain Wilkes describes† portions of vesicular lava as found among blocks of coral conglomerate at Rose Island, a small and low coral island, forming the most eastern of the Samoan group. We should expect many mixtures of volcanic rocks with coral sands and pebbles on the beaches of volcanic islands, fringed by coral reefs, as appears often to be the case, and also an occasional overflow of lava on reefs adjoining land liable to volcanic eruptions.‡

* Beete Jukes, Narrative of the Voyage of the "Fly." He describes flats of coral conglomerate, half a mile wide, as frequent along shore on the N.E. coast of Australia. Upon all these flats, and about ten feet above high-water, there is an abundance of pumice pebbles. They occur on the east coast of Australia, under similar conditions, for 2000 miles; are rarely seen on the present beach, or found floating at sea; and Mr. Beete Jukes infers, that this proves either the stationary character of the coast, or that it has been equally affected, for this distance, by elevation or depression. He allows for the piling action of the breakers, and considers it as not improbable that the coast has been slightly elevated, or, at least, has not suffered any depression through a long lapse of time.

† United States' Exploring Expedition, vol. ii., p. 64.

‡ A coral bed, ten feet thick, is stated to occur between two lava streams at the Isle of France; the coral bed elevated, since its formation, above the level of the sea.

CHAPTER XII.

TRANSPORT OF MINERAL MATTER BY ICE.—HEIGHT OF SNOW-LINE.—GLACIERS.—CAUSE OF THE MOVEMENT OF GLACIERS.—GLACIER MORAINES. MOTION OF GLACIERS.—GROOVING OF ROCKS BY GLACIERS.—ADVANCE AND RETREAT OF GLACIERS.—GLACIERS OF THE HIMALAYA.

VERY considerable attention has, of late years, been directed to the influence of ice in the distribution of detritus, both upon dry land and over the bottom of the sea, and to the mechanical effects ice may produce on hard rocks, or loose accumulations, on or against which it may move or be thrown, upon the land or beneath the sea.

We observe the influence of the sun's heat to be now such (whatever view may be taken of any supposed heat in the body of the earth itself, sufficient in previous times, to prevent the formation of ice on its surface), that the cold of the planetary space, as it has been termed, so acts upon the earth, that it is, as it were, encased in a comparatively thin warmer space, outside which, water remains permanently solid; this space having a spheroidal form somewhat more oblate than the sea-level, so that, at the equator, there is a difference of from 16,000 to 17,000 feet between the two, and that it joins that level in the Arctic and Antarctic regions. Above this, it is inferred that the temperature continues to decrease in the atmosphere until, finally, that of the planetary space alone prevails.*

Taking thus the heat derived from the sun as so influencing the present surface temperature of the earth, that the cold of the planetary space does not render the waters solid over the whole face of the world, we should, from the conditions under which this heat could prevail, anticipate many minor modifications in its

* Fourier inferred that the temperature of the planetary space was $-50°$ centigrade (58° Fahr.), and Svanberg held it was $-49°{\cdot}85$ centigrade, employing another method. Observing this near approach to the result given by Fourier, the latter calculated the temperature according to Lambert's statements, and obtained $-50°{\cdot}35$.

action.* These would arise from its different absorption and radiation according as it fell upon land or water, and in different latitudes; from the varied relief and character of the land, and its intermixture with surface waters; from the variation in the waters as to depths, and the motion of some portions of them from colder to hotter regions, or the reverse; from the movement of the atmosphere and its varied conditions; and from the periodical change in the position of portions of the earth's surface, according as one hemisphere or the other becomes most exposed to the influence of the sun.

Numerous observations have shown the exact regularity of the space, in which water commonly remains liquid, to be much disturbed by the modifications noticed; so that, for all the purposes required by the animals and vegetables of our planet, certain regions are rendered habitable which would otherwise scarcely support life. A very marked instance of this kind is found on the north flank of the Himalaya, where the perpetual snow-line, as it is termed, is, from a combination of physical conditions, more elevated by 1500 or 2000 feet than on the southern side of the same great range of mountains.† Minor modifications of the same kind are abundant, as also from the influence of great surfaces occupied by the sea, and from prevalent winds sweeping over it and reaching land; thus producing marked elevations of the general temperature above that at which ice would be common.

To obtain the snow reposing on the regions or elevated mountains, piercing through the space above noticed into those portions of our atmosphere where the temperature is such that snow more or less encrusts them during the whole of the various climatal changes of the year, we have to infer evaporation from the land and water, modified according to their various states, surfaces, and

* Respecting the temperature of our atmosphere, M. Arago has remarked, (Ann. de Phys. et de Chim., tom. 27,) that, "1st, in no part of earth on land will a thermometer, raised from two to three metres (6·5 to 10 English feet) above the ground, and protected from all reverberation, attain 46° centigrade (114°·8 Fahr.); 2ndly, in the open sea, the temperature of the air, whatever be the place and season, never attains 31° centigrade (87°·8 Fahr.); 3rdly, the greatest degree of cold which has ever been observed upon our globe, with the thermometer suspended in the air, does not descend 50° centigrade below zero (58° Fahr.)." To this he adds, "4thly, the temperature of the water of the sea, in no latitude, and in no season, rises above 30° centigrade (86°. Fahr.)."

† With reference to the snow-line on the northern flank of the Himalaya, Dr. Hooker states (letter to Sir William Hooker, dated Tongu, N.E. Sikkim, altitude 13,500 feet, July 25, 1849), "that the snow-line, in Sikkim, lies on the Indian side of the Himalayan range at below 15,000 feet; on the Thibetan (northern) slope, at about 16,000 feet."

localities, sufficient to afford the needful falls of water in this form.*

From the polar regions, where we find such a great amount of climatal change, that the influence of the sun, as far as it can be there experienced, is uninterrupted, or nearly so, during one-half of the year, and unfelt during the remainder, to the tropical regions, where portions of mountain masses may rise so high into the atmosphere as to support a covering of snow, there are necessarily great variations of temperature, the latter becoming less changeable, as a whole, in the equatorial portions of the earth.

When attention is directed to the effects arising from these variations of temperature, it is found that the production of glaciers

---

* Experiments do not seem to give the temperature at which the evaporation of snow or water ceases, so that while a limit may be inferred for this evaporation at some height to which parts of a mountain-chain might be elevated, it might readily happen that there are none such on the face of our planet, the vapour of water always mixing with the gases of the atmosphere up to all the heights in it to which parts of the earth's surface have been protruded.

Humboldt (Fragmens Asiatiques, p. 549) has given the following table of the snow-line on certain mountain ranges:—

Mountains.	Latitude.	Height above the Sea.
		English Feet.
Cordillera of Quito	0° to 1½° S.	15,730
——— Bolivia	16° ,, 17¾° S.	17,070
——— Mexico	19° ,, 19¼° N.	15,020
Himalaya:—		
Northern Flank	30¾° ,, 31° N.	16,620
Southern Flank	. .	12,470
Pyrenees	42½° ,, 43° N.	8,950
Caucasus	42½° ,, 43° N.	10,870
Alps	45¾° ,, 46° N.	8,760
Carpathians	49° ,, 49¼° N.	8,500
Altai	49° ,, 51° N.	6,400
Norway		
Interior	61° ,, 62° N.	5,400
,,	67° ,, 67¼° N.	3,800
,,	70° ,, 70¼° N.	3,500
Coast	71° ,, 71½° N.	2,340

To these may be added the following observations:—

Locality.	Latitude.	Height above the Sea.	Authority.
		English Feet.	
Bolivia	16° to 18° S.	16,263	Pentland.
Cordillera of Chili	33° S.	14,500	Gillies.
Chiloe	40° to 43° S.	6,000	Fitzroy.
Tierra del Fuego	54° S.	3,750	King.
Kamtschatka	57° N.	5,308	Erman.
Bären Island	74° 30′ N.	590	Durocher.

M. Durocher (Mémoire sur la limite des neiges perpétuelles. Voyage de la Recherche, 1845) places the line of perpetual snow in the Arctic Ocean in 78° N.; so that, at Spitzbergen (N.W. coast), it descends to the level of the sea.

stands somewhat prominently forward among those which have a geological bearing. In the Alps, Europeans have been long familiar with the elongated masses of ice, so called, descending from the regions of snows, through ravines and rocky depressions of various forms, even into fertile valleys, where ripening crops and ice may be almost in contact under the heats of summer and autumn, in latitudes ranging from 44° to 47°. De Saussure, though not the first to examine them, by the charm of his writings, directed no little attention to glaciers, and to the effects produced by them. Other authors have, at various times, since described them; and, among those of late years, M. Charpentier* and M. Agassiz† have written much in support of a particular hypothesis as to the mode in which these masses of ice moved outwards from the mountain heights whence they originated, and as to their former more considerable range and extension than at present, pointing to many circumstances connected with this subject, and of geological value, though the hypothesis itself may not be adopted.

The progress of researches respecting glaciers and their geological effects, affords a fair example of the necessity of careful observation in a right direction; so many assertions connected with the mode of occurrence and advance of these masses of ice, upon which hypotheses were based, having been found, upon actual investigation, unsupported by facts. Though this has been the case, many observations have, from time to time, been recorded, which have borne the test of careful investigation; and no one would appear more desirous of admitting the value and importance of real additions to our information on this subject, than Professor James Forbes, to whom so much of our present knowledge of the Alpine glaciers is due.‡

A glacier commences near the line of perpetual snow, but lower somewhat than that on the adjacent ground. "There is often a passage, nearly insensible, from perfect snow to perfect ice; at other times, the level of the superficial snow is well marked, and the ice occurs beneath it. No doubt the transition is effected in this way: —the summer's thaw percolates the snow to a great depth with water; the frost of the succeeding winter penetrates far enough to

* "Essai sur les Glaciers et sur le Terrain Erratique du Bassin du Rhone," 1841. Lausanne.

† "Études sur les Glaciers," 1840. Neuchatel.

‡ See his Travels through the Alps of Savoy and parts of the Pennine Chain, with observations on the Phenomena of Glaciers, 2nd edit., Edinburgh, 1845; and his papers printed in the Philosophical Transactions, for 1846.

freeze it at least to the thickness of one year's fall, or, by being repeated in two or more years, consolidates it more effectually."* The part of a glacier, where the surface begins to be annually renewed by the unmelted accumulation of each winter, is commonly known as *névé,* and true stratification has been here recognized by De Saussure and other writers. Professor Forbes agrees with M. de Charpentier† in thinking that this stratification becomes entirely obliterated as the *névé* passes into complete ice.‡ The *crevasses,* or great fissures, in the *névé* are considered to differ from those lower down the glacier in their greater width and irregularity, and the caverns in it to be more extensive and singular in their forms, from the greater facility with which the *névé* is thawed and water-worn.

Further down the valley, or ravine, in which the glacier finds its way, much will necessarily depend, as to the form and appearance of the latter, upon the general character of the ground traversed. The ice changes its character: it is not like that produced by the freezing of still water in the lake, but "laminæ, or thin plates of compact transparent blue ice, alternate, in most parts of every glacier, with laminæ of ice not less hard and perfect, but filled with countless air-bubbles, which give it a frothy semi-opaque look." "The alternation of bands, then, is marked by blue and greenish-blue or white curves, which are seen to traverse the ice throughout its thickness whenever a section is made. It is, therefore, no external accident—it is the internal structure of a glacier, and the only one which it possesses, and may be expected to throw light upon the circumstances and formation of these masses."§

* Forbes' Travels through the Alps of Savoy, 2nd edit., p. 31.

† For his views respecting glaciers, consult M. de Charpentier's Essai sur les Glaciers et sur le Terrain Erratique du Bassin du Rhone. Lausanne, 1841.

‡ "The granulated structure of the névé is accompanied with the dull white of snow passing into a greenish tinge, but rarely, if ever, does it exhibit the transparency and hue of the proper glacier. The deeper parts are more perfectly congealed, and the bands of ice, which often alternate with the hardened snow, are probably due to the effect of thaw succeeding the winter coating, or any extraordinary fall. On exposed summits, where the action of the sun and the elements is greater, the snow does not lie so long in a powdery state, and the exposed surface becomes completely frozen." Forbes' Travels through the Alps, &c., 2nd edit., p. 32.

§ Forbes' Travels through the Alps, &c., 2nd edit., p. 28. It is remarked, respecting this structure, that it is the consequence of the viscous condition of the mass and its movement. It is observed that it "has all the appearance of being due to the formation of fissures in the aërated ice or consolidated névé, which fissures having been filled with water drained from the glacier, and frozen during winter, have produced the compact blue bands" (p. 372). Professor Forbes considers, that, as the viscous mass moves onward, the central parts faster than the sides, these fissures, filled with ice, take a more horizontal position in the general mass, with such modifications as may be expected on the sides and bottom where the friction is greatest,

Below the *névé*, the glacier commonly finds its way, amid various depressions of different forms, to the lower ground, far beneath the line which marks the usually constant presence of snow throughout the year. The accompanying view (fig. 84, p. 212) of Mont Blanc, taken from the Bréven, a mountain rising high above the valley of Chamonix, which separates the Bréven from the Mont Blanc, will give a better idea of the passage of the glaciers downwards into the lower valley, than a verbal description, and more especially as the altitude and position of the Bréven itself prevents that foreshortening and less instructive view obtained from beneath.

As the great icy mass descends from the region of the *névé* to the lower ground, the *crevasses* vary much in length and breadth, sometimes extending across the whole glacier,* and this, as might be expected, according to the character of the surface on which it may repose. As it descends into warmer regions, the glacier is necessarily exposed to the influence of higher temperature, and if it did not obtain the needful supply from above, it would there diminish in bulk and disappear. As this supply varies, the extension of a glacier will correspond with the kind of seasons experienced, so that it may descend further into the lower valleys at one time than another;† and thus its actual amount of protrusion into a valley may depend, for the time, upon effects produced through many seasons, and be liable to frequent change.

---

accompanying his remarks by ideal sections of glaciers and real sections of viscous bodies experimented upon for illustration. He observes, "that this ribboned structure follows a very peculiar course in the interior of the ice, of which the general type is the appearance of a succession of oval waves on the surface, passing into hyperbolas, with the greater axis directed along the glacier. That this structure is also developed throughout the thickness of a glacier, as well as from the centre to the side, and that the structural surfaces are twisted round in such a manner, that the *frontal dip*, as we have called it, of the veins, as exhibited on a vertical plane cutting the axis of a glacier, occurs at a small angle at its lower extremity, and increases rapidly as we advance towards the origin of the glacier" (p. 372).

* In the account of his passage over the Col de Géant, Professor Forbes mentions an immense chasm or crevasse, extending wholly across a glacier in the descent on the Chamonix side, and at least 500 feet in width. "It terminated opposite to the precipices of the Aiguille Noire in one vast *enfoncement* of ice, bounded on the hither side by precipices not less terrible." Travels through the Alps &c., p. 238.

† Among the numerous examples of the varied extension and volume of glaciers known in modern times, there would appear none more illustrative than that of the Brenva, on the Italian side of Mont Blanc. In 1818 it attained a height different from that found by Professor Forbes, in 1842, of at least 300 feet, as proved by that of a rock, upon which a well-known chapel (Chapelle de Berriér) was placed, which, with the rock on which it stood, was heaved and fissured by the rise of the ice. This great increase of volume, and its decrease in the 24 years, is well attested. The Professor remarks, that the mean temperature for the five years preceding 1818, when the glacier was thus of such increased volume, presented no marked change, the mean temperature at Geneva being for that time 7°·61, Reaumur (49°·12 Fahr.); the mean for the last 40 years, in the same town, being 7°·75 (49°·44 Fahr.)—Travels, &c., p. 205.

freeze it at least to the thickness of one year's fall, or, by being repeated in two or more years, consolidates it more effectually."* The part of a glacier, where the surface begins to be annually renewed by the unmelted accumulation of each winter, is commonly known as *névé*, and true stratification has been here recognized by De Saussure and other writers. Professor Forbes agrees with M. de Charpentier† in thinking that this stratification becomes entirely obliterated as the *névé* passes into complete ice.‡ The *crevasses*, or great fissures, in the *névé* are considered to differ from those lower down the glacier in their greater width and irregularity, and the caverns in it to be more extensive and singular in their forms, from the greater facility with which the *névé* is thawed and water-worn.

Further down the valley, or ravine, in which the glacier finds its way, much will necessarily depend, as to the form and appearance of the latter, upon the general character of the ground traversed. The ice changes its character: it is not like that produced by the freezing of still water in the lake, but "laminæ, or thin plates of compact transparent blue ice, alternate, in most parts of every glacier, with laminæ of ice not less hard and perfect, but filled with countless air-bubbles, which give it a frothy semi-opaque look." "The alternation of bands, then, is marked by blue and greenish-blue or white curves, which are seen to traverse the ice throughout its thickness whenever a section is made. It is, therefore, no external accident—it is the internal structure of a glacier, and the only one which it possesses, and may be expected to throw light upon the circumstances and formation of these masses."§

---

* Forbes' Travels through the Alps of Savoy, 2nd edit., p. 31.

† For his views respecting glaciers, consult M. de Charpentier's Essai sur les Glaciers et sur le Terrain Erratique du Bassin du Rhone. Lausanne, 1841.

‡ "The granulated structure of the névé is accompanied with the dull white of snow passing into a greenish tinge, but rarely, if ever, does it exhibit the transparency and hue of the proper glacier. The deeper parts are more perfectly congealed, and the bands of ice, which often alternate with the hardened snow, are probably due to the effect of thaw succeeding the winter coating, or any extraordinary fall. On exposed summits, where the action of the sun and the elements is greater, the snow does not lie so long in a powdery state, and the exposed surface becomes completely frozen." Forbes' Travels through the Alps, &c., 2nd edit., p. 32.

§ Forbes' Travels through the Alps, &c., 2nd edit., p. 28. It is remarked, respecting this structure, that it is the consequence of the viscous condition of the mass and its movement. It is observed that it "has all the appearance of being due to the formation of fissures in the aërated ice or consolidated névé, which fissures having been filled with water drained from the glacier, and frozen during winter, have produced the compact blue bands" (p. 372). Professor Forbes considers, that, as the viscous mass moves onward, the central parts faster than the sides, these fissures, filled with ice, take a more horizontal position in the general mass, with such modifications as may be expected on the sides and bottom where the friction is greatest,

Below the *névé*, the glacier commonly finds its way, amid various different forms, to the lower ground, far beneath the line which marks the usually constant presence of snow throughout the year. The accompanying view (fig. 84, p. 212) of Mont Blanc, taken from the Bréven, a mountain rising high above the valley of Chamonix, which separates the Bréven from the Mont Blanc, will give a better idea of the passage of the glaciers downwards into the lower valley, than a verbal description, and more especially as the altitude and position of the Bréven itself prevents that foreshortening and less instructive view obtained from beneath.

As the great icy mass descends from the region of the *névé* to the lower ground, the *crevasses* vary much in length and breadth, sometimes extending across the whole glacier,* and this, as might be expected, according to the character of the surface on which it may repose. As it descends into warmer regions, the glacier is necessarily exposed to the influence of higher temperature, and if it did not obtain the needful supply from above, it would there diminish in bulk and disappear. As this supply varies, the extension of a glacier will correspond with the kind of seasons experienced, so that it may descend further into the lower valleys at one time than another;† and thus its actual amount of protrusion into a valley may depend, for the time, upon effects produced through many seasons, and be liable to frequent change.

---

accompanying his remarks by ideal sections of glaciers and real sections of viscous bodies experimented upon for illustration. He observes, "that this ribboned structure follows a very peculiar course in the interior of the ice, of which the general type is the appearance of a succession of oval waves on the surface, passing into hyperbolas, with the greater axis directed along the glacier. That this structure is also developed throughout the thickness of a glacier, as well as from the centre to the side, and that the structural surfaces are twisted round in such a manner, that the *frontal dip*, as we have called it, of the veins, as exhibited on a vertical plane cutting the axis of a glacier, occurs at a small angle at its lower extremity, and increases rapidly as we advance towards the origin of the glacier" (p. 372).

* In the account of his passage over the Col de Géant, Professor Forbes mentions an immense chasm or crevasse, extending wholly across a glacier in the descent on the Chamonix side, and at least 500 feet in width. "It terminated opposite to the precipices of the Aiguille Noire in one vast *enfoncement* of ice, bounded on the hither side by precipices not less terrible." Travels through the Alps &c., p. 238.

† Among the numerous examples of the varied extension and volume of glaciers known in modern times, there would appear none more illustrative than that of the Brenva, on the Italian side of Mont Blanc. In 1818 it attained a height different from that found by Professor Forbes, in 1842, of at least 300 feet, as proved by that of a rock, upon which a well-known chapel (Chapelle de Berriér) was placed, which, with the rock on which it stood, was heaved and fissured by the rise of the ice. This great increase of volume, and its decrease in the 24 years, is well attested. The Professor remarks, that the mean temperature for the five years preceding 1818, when the glacier was thus of such increased volume, presented no marked change, the mean temperature at Geneva being for that time 7°·61, Reaumur (49°·12 Fahr.); the mean for the last 40 years, in the same town, being 7°·75 (49°·44 Fahr.)—Travels, &c., p. 205.

Fig. 84.

MER DE GLACE AND GLACIER DES BOIS. CHAMONIX. GLACIER DE BOISSONS.

The turbid waters, rushing out from beneath the glaciers of the Alps will be familiar to all who have visited these mountains, as also the caverns of ice through which these waters commonly find their way when they are most abundant. With respect to such waters, Professor Forbes has pointed out that they may not only be due to the ice melted by contact with the rocks on which it moves, to the fall of rain upon the ice drained by the glacier valley, in the season when rain falls, and to the waste of the glacier itself by the sun and rain, but also to the natural springs rising from beneath the ice, as in any other locality.*

With respect to the cause producing the motion of glaciers, different views have been taken:† Professor James Forbes considers it as "convincingly proved,‡ that the motion of a glacier varies not only from one season to another, but that it has definite (though continuous) changes of motion, simultaneous throughout the whole, or a great part of its extent, and therefore due to some general external change," and that "this change has been shown to be principally or solely the effect of the temperature of the air, and the conditions of wetness or dryness of the ice."§ With regard to the movement itself, the Professor has pointed out "that the ice does not move as a solid body,—that it does not slide down with uniformity in different parts of its section,—that the sides which might be imagined to be most completely detached from their rocky walls during summer, move slowest, and are, as it were

* With respect to the waste of the glacier by the sun and rain, Professor Forbes remarks, that it is "a most important item, and which constitutes the main volume of most glacier streams, except in the depth of winter. It is on this account that the Rhine and other great rivers, derived from Alpine sources, have their greatest flood in July, and not in spring or autumn, as would be the case if they were alimented by rain-water only. On the same account, the mountain torrents may be seen to swell visibly, and roar more loudly, as the hotter part of the day advances, to diminish towards evening, and in the morning to be smallest." "Winter is a long night amongst the glaciers. The sun's rays have scarcely power to melt a little of the snowy coating which defends the proper surface of the ice; the superficial waste is next to nothing, and the glacier torrent is reduced to its narrowest dimensions."—Travels through the Alps of Savoy, &c., 2nd edit., pp. 20, 21.

† The chief of these views will be found in the works of MM. de Saussure, De Charpentier, Agassiz, Élie de Beaumont, Mr. William Hopkins, and of Professor James Forbes. In the latter they will be seen discussed in much detail, and the Professor's own views advocated, especially in his Travels through the Alps of Savoy, &c., in chap. xxi. (entitled "An attempt to explain the leading Phenomena of Glaciers"), and in his papers entitled "Illustrations of the Viscous Theory," published in the Philosophical Transactions for 1846. A very detailed account of the works and views respecting glaciers will also be found in the Histoire des Progrès de la Géologie, de 1834-1845, by the Vicomte d'Archiac, Paris, 1847.

‡ Travels through the Alps of Savoy, &c., and alluding to chap. vii.

§ Ib., chap. xxi., p. 363.

dragged down by the central parts." * His theory is, that "a glacier is an imperfect fluid, or a viscous body, which is urged down slopes of a certain inclination by the mutual pressure of its parts." † He does not, however, "doubt that glaciers slide on their beds, as well as that the particles of ice rub over one another, and change their mutual positions." ‡

The movement of glaciers is important as regards the transport of mineral substances, inasmuch as by it they bear onwards upon their surfaces any fragments of rock that may fall upon them from the heights amid which they pass; thrust before them any loose accumulations of blocks, gravel, sand, and earth which may oppose their course, and even break off portions of rocks where the resistance of the latter is less than the force of the glacier, divisional planes, such as joints and cleavage, with the natural bedding of rocks, often rendering the mass of such rocks less resistant than it would otherwise be. The observer, accustomed often to see the steep cliffs of many a mountain region covered towards their bases

---

* Travels through the Alps of Savoy, &c. chap. xxi. p. 363. As to the different rates of motion of a glacier, it is observed that a glacier, "like a stream, has its still pools and its rapids. Where it is embayed by rocks it accumulates—*its declivity diminishes, and its velocity, at the same time.* When it passes down a steep, or issues by a narrow outlet, its velocity increases. The *central* velocities of lower, middle, and higher regions of the Mer de Glace are—1·398, ·574, and ·925; and if we divide the length of the glacier into three parts, we shall find these numbers for its declivity, 15°, 4½°, and 8°.—Forbes' Travels, &c., p. 371.

† Ib., p. 365. It would be somewhat out of place in this work to enter more fully into the theory of glacier movements. Respecting the theory of the viscous condition of a glacier, Professor Forbes alludes to its spreading as a viscous body would do when a glacier passes out of a narrow gorge into a wide valley, stating that this fact had been first brought prominently forward by M. Rendu, now Bishop of Annecy (Travels, p. 367.) M. Rendu (Théorie des Glaciers de la Savoie, Chambery, 1840) divides glaciers into *glaciers réservoirs* and *glaciers d'écoulement*, the former in the high regions, and the latter descending into the lower valleys. He estimates the height of the separation between the two in Savoy at 2,923 metres (9,590 English feet). He points to the accumulation of snow in the higher regions, the rain, when it falls there, freezing, and to the feeding of the lower glaciers by the descent of this snow and ice.

‡ "But," he adds, "I maintain that the former motion is caused by the latter, and that the motion impressed by gravity upon the superficial and central parts of a glacier (especially near its lower end), enables them to pull the lateral and inferior parts along with them. One proof, if I mistake not, of such an action is, that a deep current of water flows under a smaller declivity than a shallow one of the same fluid. And this consideration derives no slight confirmation, in its application to glaciers, from a circumstance mentioned by M. Élie de Beaumont, which is so true that one wonders that it has not been more insisted on—namely, that a glacier, where it descends into a valley, is like a body, pulled asunder or stretched, and not a body forced on by superior pressure alone" (p. 370). In a note to this passage, the Professor remarks, "that a state of universal distension, or a state of universal compression, is equally incompatible with the existing phenomena of most glaciers, and that compression in some parts and distension in others are plainly indicated by their natural features."

by the débris detached by atmospheric influences from above, and especially in climates or regions where frosts and thaws often alternate, would readily expect these fragments to move onwards with the glacier on the edges of which they may fall.* Instead, therefore, of accumulating in a talus of débris, as can be well studied in many mountainous regions, the mass of fragments moves slowly onwards, and the protection from atmospheric influences afforded by this talus to the solid rocks beneath it (in some mountain countries collectively very considerable), is removed precisely in localities where the vicissitudes of climate are often so great that it can be the least spared.

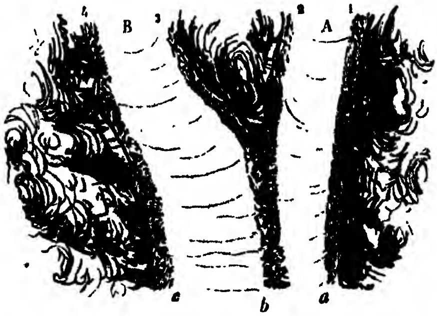
The blocks and smaller fragments (necessarily very variable in form and volume, according to the character of the overhanging rocks, and the amount of their decomposition anterior to their fall), thus strewed upon the glaciers, are well known as *moraines*.† These moraines also necessarily differ in general volume, according to the amount of matter which may be detached from the heights above the glacier, and the rate of movement of the glacier itself on the sides adjoining the sources of the detached fragments. Two lines of moraine will mark the edges of a glacier, should the heights on either side of it afford the needful supply, as also a mass of rock rising through a glacier, should it also afford fragments, as has been pointed out by Professor Forbes. When two or more streams of glaciers unite, each bearing its two, or even as we have seen, three lines of rock fragments, the union will so dispose of the lines as to form a less number for the remaining course of the glacier, as in fig. 85, where the glaciers coming down the valleys A and B, and uniting the four moraines, two on the sides of each glacier, become three (*a*), (*b*), (*c*), by the union of the lateral moraines 2 and 3 into a central moraine (*b*). Various other unions, easily imagined, are produced, as minor contribute to main glaciers. A great central moraine may be established by the junction of two long lines of glacier sides, unbroken for a considerable distance, and upon which

* The débris on mountain sides often completely masks their character as left anterior to such coverings. There are few mountainous regions which do not show this when carefully examined. Mining operations often prove it on the sides of hills. Ravines, where ravines may not be uncommon, are usually favourable for observations of this kind; as, for example, many instances are found in Derbyshire, where the faces of steep cliffs are often modified in this manner, the long-continued action of atmospheric influences having smoothed off many a precipitous hill side, where the same effects may be seen in daily progress. This action has greatly modified the face of most countries, especially when combined with landslips.

† This name has become common with us from the works of De Saussure and others writing in French. *Guffer* is the German term for them.

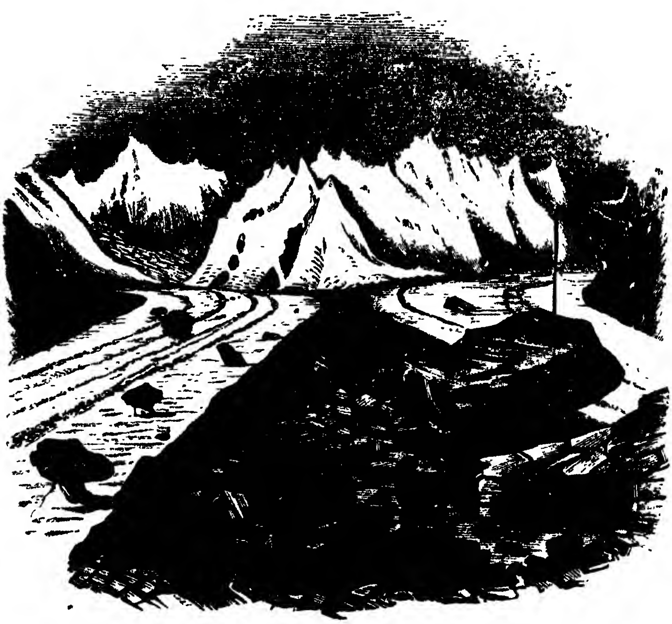
a great fall of fragments may take place, while the opposite sides may be marked with slighter lines of moraine, derived from tributaries receiving a less amount of fragments.

Fig. 85.



The following view (fig. 86), representing the upper part of the glacier of the Aar,* well shows the lines of moraine coming down from the glacier of the Finsteraarhorn, on the left, and from that

Fig. 86.



of the Lauteraarhörner, on the right. It also illustrates the formation of a single line of moraine in the centre, by the union of the

* Reduced from a view in the Études sur les Glaciers by Agassiz. Neuchatel, 1840.

two lateral moraines of the glaciers above noticed. Examples are also seen of the mushroom-like appearance produced by the unequal melting of the surface of a glacier, so that protection being afforded, as long since pointed out by De Saussure, by a block of rock (particularly if it has so fallen on the glacier as to rest in a tabular manner), the ice beneath has not disappeared so rapidly as around it, and thus the block is raised upon a stem of ice. Some of the blocks thus supported are very large.* It is, in the same manner, to the protection from the sun and rain afforded to the ice beneath by the mass of the moraine, that it often rises above the ice.†

The following view ‡ (fig. 87, p. 218), of the upper part of the glacier of Zermatt, also shows the effects produced, as regards moraines, by the union of glaciers. On the left, the lines of moraine are derived from the glacier of Monte Rosa and of the Gornerhorn, with the lateral moraine of the foot of the Riffelhorn and the great moraine of the Breithorn. On the right are the glaciers of the Little Cervin and of the Furke-flue. The *crevasses* across the united glaciers are well exhibited in front, as also the rise of the ice above the side of the glacier, showing that the blocks and other rock fragments, there borne onwards, would have a tendency to fall over and accumulate in a lateral moraine, off the ice, and upon the adjoining lower ground.

If the rate of movement of a glacier depends upon the slope and

* A large one, observed by Professor Forbes in 1842, is represented in his Travels through the Alps, &c., pl. 1, and he gives the following instructive account of it:— "There lies on the ice a very remarkable flat block of granite, which particularly attracted my attention on my first visit in 1842 to that part of the glacier. It is a magnificent slab, of the dimensions of 23 feet by 17, and about 3½ in thickness. It was then easily accessible, and by climbing upon it and erecting my theodolite, I made observations on the movement of the ice; but as the season advanced it changed its appearance remarkably. In conformity with the known fact of the waste of the ice at its surface, the glacier sunk all round the stone, while the ice immediately beneath it was protected from the sun and rain. The stone thus appeared to rise above the level of the glacier, supported on an elegant pedestal of beautifully veined ice. Each time that I visited it, it was more difficult of ascent, and on the 6th August, the pillar of ice was *thirteen feet high*, and the broad stone so delicately poised on the summit of it (which measured but a few feet in any direction), that it was almost impossible to guess in what direction it would ultimately fall, although by the progress of the thaw, its fall in the course of the summer was certain. During my absence in the end of August, it slipped from its support, and in the month of September it was beginning to rise on a new one, whilst the unmelted base of the first was still very visible on the glacier." (p. 92.)

† The glacier cones, as they are called, are accounted for on the same principle of protection from the influence of the sun, sand washed by rain-water into cavities on the glacier finally so accumulating that it prevents the melting of the ice beneath at the rate experienced around, so that the sand still remaining on the ice, the latter takes the form of a cone with a sandy covering. They have been found 20 to 30 feet in height, and 80 to 100 feet in circumference.—Agassiz, Études sur les Glaciers, chap. x., and Forbes' Travels, &c., chap. ii., p. 26.

‡ Also taken from the Études sur les Glaciers, by Agassiz.

form of the subjacent and boundary rocks, all other conditions being equal,* we should expect it to vary very materially in the course of the same glacier, and in different glaciers. The very

Fig. 87.

careful investigations of Professor James Forbes have proved the correctness of the view taken by M. Rendu,† that the central portions move faster than the lateral,‡ so that the blocks and frag-

* When the rates of advance of different glaciers are compared with the slopes on which they move, it is very essential to take all other conditions into account, a precaution which does not appear to have been always adopted.

† Théorie des Glaciers de la Savoie, p. 63.

‡ Travels through the Alps of Savoy, &c., chap. vii., entitled "Account of Experiments on the Motion of the Ice of the Mer de Glace of Chamouni." The means adopted were of an order to insure success. The Professor selected a point on the ice, and determined its position with respect to three fixed co-ordinates, having reference to the fixed objects around. He found, after the observations of four days, that the ice on which his instrument was placed moved during each 24 hours at the rate of

15·2 : — 16·3 : — 17·5 : — 17·4 inches,

a variation which he considered due to the increasing heat of the weather. On trying the rate of nocturnal motion, as compared with the diurnal, the Professor found exactly one-half, the night having been cold. The general motion was not by fits of advance and halts, but orderly and continuously. By well-considered arrangements, he also found that the somewhat common opinion of the sides of a glacier moving

ments of the medial lines of moraine descend further in less time than those on the sides, even when the latter are not thrown over, and left on the ground bounding the sides of a glacier. From the nature of the transport, any enormous mass of rock, detached from a height above a glacier, will move as readily onwards as a small fragment; indeed, from its protecting influence against the action of the sun and rain, it would tend to preserve the ice beneath far more effectually, considering the subject generally; not, however, forgetting that from the unequal melting of the ice around and partly beneath, it may be tilted off, not only into a crevasse, where it might advance with the general march of the glacier, but also into some situation where its progress may, for a time at least, be arrested. Some of the blocks observed on the glaciers are of very considerable dimensions. Professor Forbes mentions having seen one on the ice of the glacier of Viesch, in the Valais, nearly 100 feet long, and 40 or 50 feet high.*

---

faster than the centre was incorrect, and that, on the contrary, their motion was slower. From the 29th June to the 1st July (1842), while the sides of the part of the Mer de Glace experimented upon moved at a rate of 17·5 inches for each 24 hours, the centre advanced 27·1 inches. Other experiments on other parts of the glacier led to similar results. It was found that, "(1) The motion of the higher parts of the Mer de Glace is, as a whole, *slower* than that of its lower portion, but the motion of the middle region is slower than either. (2) The Glacier de Géant moves faster than the Glacier de Léchaud. (3) The centre of the glacier moves faster than the sides. (4) The difference of motion of the centre and sides of the glacier varies with the season of the year, and at different parts of the length of the glacier; and (5) The motion of the glacier generally varies with the season of the year and the state of the thermometer." Subsequent investigations enabled Professor Forbes to state (Philosophical Transactions, 1846, "Illustration of the Viscous Theory of Glacier Motion," parts 1, 2, and 3), that the movement of the Mer de Glace went on continuously for several days, and he gives a valuable table of the apparent and relative motion of 45 points, two feet apart, in a line traversing the axis of this glacier, in 1844 (p. 171).

The motion of a particular stone, named the Pierre Platte, on the Mer de Glace, was observed to be as follows:—

From the 17th September, 1842, to 12th September, 1843, the advance in 360 days was	256·8 feet.
Reduced to the year of 365 days	260·4 ,,
Mean daily motion	8·56 inches.
From 12th September, 1843, to 19th August, 1844, 342 days	270 feet.
Proportional motion for 365 days	288·3 ,,
Mean daily motion	9·47 inches.

There are also important tables of the motion observed at two stations on the Glacier des Bois (one observed from the 2nd October, 1844, to the 21st November 1845, and the other from 4th December, 1844, to 21st November, 1845); and at two stations on the Glacier des Boissons (one from 20th November, 1844, to 22nd November, 1845, and the other from 2nd October, 1844, to 22nd November, 1845), showing the variable, but continued progress, of these glaciers during the intervals. Among the results, it appeared that "in both glaciers the summer motion exceeds the winter motion in a greater proportion as the station is lower, that is, exposed to more violent alternations of heat and cold."

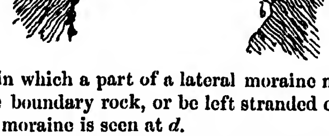
* Travels, &c., p. 46. A very large granite block, also seen by the Professor upon the Mer de Glace, in 1842, is figured by him in the same work, p. 57.

While thus fragments of all dimensions, and in great abundance, find their way with an unequal rate of movement, according to their position on a glacier, to lower levels, numerous others are arrested in their progress, tilted off and left on the ground adjoining its sides, should circumstances permit. When a glacier so changes its volume as to occupy a higher relative level at one time than another, amid the mountain depressions and ravines over and through which it may move, and the conditions for leaving marginal accumulations of rock fragments on the outside of it obtain, such accumulations, should the ice afterwards decrease in volume, would remain to attest this previous state of the glacier.* No marks of this kind would be left where the sides of a ravine or cliff were so steep that the blocks could not find rest. The fragments would either rise or descend with the glacier, some probably falling into any space left between the ice and the wall of rock, and open either from a certain amount of melting of the glacier at its contact with the rock, or from the passage of the mass of ice along the uneven front of a cliff, cavities of different kinds thus presenting themselves.

From fragments of rock becoming jammed between the ice of a glacier and its rocky walls, as cannot fail often to be the case, and indeed is well known, the friction of these fragments, pressed by the great force of the glacier, grooves and furrows the adjoining rocks in lines corresponding with their motion. Professor Forbes gives the following interesting view (fig. 89) of the 'Angle,' Mer de Glace, where granite blocks are jammed in between the ice and the rock, wearing "furrows in the retaining wall, which is all freshly streaked, near the level of the ice, with distinct parallel lines, resulting from this abrasion. The juxtaposition of the power, the tool, and the matter operated on, is such as to leave not a moment's doubt that such striæ must result, even if their presence could not be directly proved."† This friction alone would tend to

* Professor Forbes (Travels, &c., p. 24) has given a very illustrative section (fig. 88), showing the manner in which fragments (c) of rock may be left by the de-

Fig. 88.



crease of a glacier, and in which a part of a lateral moraine may fall into a cavity, *a*, between the ice and the boundary rock, or be left stranded on an inclined shore, *b*. The section of a central moraine is seen at *d*.

† Travels, &c. The woodcut is a reduced sketch from pl. 3, p. 76.

reduce the fragments to less size, and even to fine powder. Looking at the general conditions of glacier movements, the kind of ground these masses of ice pass over, and to the introduction of fragments from the sides, and even through the crevasses to the bottom, we

Fig. 89.

should expect that the grooving and scratching would be considerable on the bottom and sides, mingled with an extensive smoothing of surface, as if, in the application of a huge polishing apparatus, acting, as a whole, with minor deviations, in one direction, harder grains were strewed about, so that scratching as well as polishing was effected.* This scratching and smoothing by glaciers has been chiefly observed, with reference to their geological value, in modern times, though the rounded and polished surfaces frequently seen have been long known by the name of *Roches Moutonnées*, that assigned them by De Saussure.

From the general grinding of glaciers on their beds, the friction

* Though the grooves are usually long, parallel, and polished, the minor scratches often cross each other.

of the fragments on each other, and the decomposition of many kinds of rock in regions where the alternations of frost and thaw are so common, particularly in the warmer parts of the year, much finely-comminuted mineral matter could scarcely fail to be exposed to the action of any running water, finding its way amid the glacier, and along its sides and bottom.* The streams and rivers derived from glaciers have commonly a marked character, as above noticed, from the quantity of fine mineral matter in mechanical suspension. These sometimes fall into lakes, and leave the fine sedimentary matter behind them, as is the case with many amid and on the skirts of the Alps, while some have a considerable course, as, for example, the Durance (bearing the glacier waters of Monte Viso), and many tributaries of the Po, fed by glacier streams from the southern side of Mont Blanc, and other Italian portions of the high Alps.

Independently of the mass of fragments which may be borne forward by a glacier, when it is on the increase outwards, from a fitting combination of conditions, it ploughs up the ground before it, thrusting forward the loose substances, no matter how accumulated, and with them, should they come in its course, fields, woods, and houses. We remember seeing the Glacier des Bois thus crushing and forcing all before it during its advance in 1819.† These accumulations, to which the transported blocks and minor fragments of rock are being added, as the ice melts, which once supported and carried them onwards,‡ are known as terminal moraines, and by their position a glacier is inferred to

* There is much finely-comminuted mineral matter distributed over some parts of many Alpine glaciers. It is sometimes so fine as to enter the interstices of the more porous ice, thus distinguishing the latter from the more compact bands. These "dirt bands," as Professor Forbes terms them, were of much service to him in his examination of the structure of glaciers. Alluding to the discoloration from this finely-comminuted detritus, the Professor observes, "The cause of the discoloration was the next point, and my examination satisfied me, that it was not, properly speaking, a diversion of the moraine, but that the particles of earth and sand, or disintegrated rock, which the winds and avalanches and water-runs spread over the entire breadth of the ice, *found a lodgement* in those portions of the glacier where the ice was most porous, and that consequently the 'dirt bands' were merely *indices of a peculiarly porous veined structure traversing the mass of the glacier in these directions.*"—Travels, &c., p. 163. Upon careful examination these "dirt bands" were found to be quite superficial.

† In 1820 it attained its greatest known modern advance into the valley of Chamonix.

‡ Respecting the blocks and fragments of rocks thus carried outwards, M. Rendu has remarked that some of them can be occasionally traced to the very commencement of a glacier.—Théorie des Glaciers de la Savoie.

be, for the time, either retreating, advancing, or stationary.* That glaciers advance and decrease is well known, and this to considerable distances, so that many a terminal moraine left at one time, may be again forced forward at another, part of it so caught in the advance of the ice as to be employed in grooving and scratching the solid rocks beneath, then bared and passed over by the glacier. Enormous blocks† are often left by glaciers in their retreat; indeed, under such circumstances, they would not only leave the terminal moraines, marking their extension for the time, and during periods of increase, but also their whole load of blocks and fragments, up to the new limits of the decreased glaciers.

Supposing a glacier to advance and retreat from causes which, though variable on the minor scale, are constant for considerable intervals of time, there would be no small amount of blocks and fragments of rock, too considerable to be borne onwards by river action, left either perched on various parts of the mountain sides, or distributed over the valleys, within the range of increase and decrease of these masses of ice in glacier regions. This great and constant general action, continued through long time, would scarcely otherwise than very considerably modify the state of the area from that original condition, when the glaciers were first formed, even supposing no alteration in the relative level, as respects the sea, of the mountain masses amid which they occur. Avalanches aid in the general descent of fragments of rocks, carrying many, with their snows, to lower levels, sometimes falling on glaciers, sometimes into deep valleys, where the fragments are merely exposed to the ordinary action of rivers.

Taking the general causes and movements of glaciers in the Alps for his guides, the observer is enabled to infer how far glaciers would be found in other regions. M. Élie de Beaumont has pointed out,‡ that from the little variation of climatal con-

* Professor Forbes, after quoting M. Venetz (vol. i. of the Transactions of the Swiss Nat. Hist. Society), as pointing out "that passes the most inaccessible, traversed now, perhaps, but once in twenty years, were frequently passed on foot, sometimes on horseback, between the eleventh and fifteenth centuries," considers the evidence important, as "showing that a *very notable* enlargement of these boundaries (glacier boundaries), was consistent with the limits of atmospheric temperature, which we know that the European climate has not materially overpassed within historic times."—Travels, &c., pp. 43, 44.

† Professor Forbes mentions one of green slate, pushed forward by the glacier of Swartzberg, valley of Saas, and now left at a distance of about half a mile from the glacier by its retreat, estimated by M. Venetz to contain 244,000 cubic feet. This mass, if about 14 cubic feet be taken to the ton, would weigh no less than 17,428 tons.

‡ Remarques sur deux points de la Théorie des Glaciers, Annales des Sciences Géologiques, 1842. He observes that glaciers being due to annual and not merely to diurnal conditions, there could be only perpetual snows, and not glaciers, under the equator, where the variations of temperature are only diurnal.

ditions in tropical regions, glaciers would not be expected among the mountains there situated, and sufficiently high to be clothed with perpetual snow. Where the alternations of frost and thaw, snow and rain, would be insufficient to produce the needful amount of névé, assuming this to be the storehouse whence the glaciers are supplied, these would not be found. Looking, therefore, at the different known regions of the world, their varied relief, as regards the distribution of high and low land, the different amount of water supply from the atmosphere, either in the shape of snow, hail, or rain; changes of temperature during various times of the year, and their amount; prevalent or periodical winds —one set dry, the other bringing abundant moisture, and proximity or distance from the sea—the observer finds no want of modifying conditions for the presence or absence, and geological importance of glaciers. At one time glaciers were somewhat doubted among the great range of the Himalaya, but several are now known. The height of the lowest part of the Pinder glacier is estimated at about 11,300 feet above the sea, and that of the Kuplinee glacier at 12,000, which, the height of the perpetual snow line near them being considered at about 15,000 feet, would give a glacier descent of 3,700 feet for the former, and 3,000 feet for the latter.* The lowest part of the glacier of the Ganges is 12,914 feet above the sea, according to Captain Hodgson.

* Captain Strachey, Bengal Engineers, Jameson's Edinburgh New Phil. Journal, vol. xliv., p. 119, and Journal of the Asiatic Society of Bengal, No. viii., p. 794.

CHAPTER XIII.

ARCTIC GLACIERS REACHING THE SEA.—NORTHERN ICEBERGS AND THEIR EFFECTS.—ANTARCTIC GLACIERS AND GREAT ICE BARRIER.—GEOLOGICAL EFFECTS OF ANTARCTIC ICEBERGS.—GLACIERS OF SOUTH GEORGIA.—GLACIERS OF SOUTH AMERICA.—TRANSPORT OF DETRITUS BY RIVER ICE.—GEOLOGICAL EFFECTS OF COAST ICE.—EFFECTS OF GROUNDED ICEBERGS.—GENERAL GEOLOGICAL EFFECTS OF ICE.

PROCEEDING from the temperate parts of the world, where lands rise sufficiently high into the atmosphere to obtain a constant covering of snow, and the fitting conditions permit glaciers to descend amid the adjacent valleys at lower levels,* to the Arctic and Antarctic regions, we find glaciers not only covering various portions of land, but jutting into the sea, the line of perpetual snow having descended towards its level. If the observer will in imagination, and by reference to the view of part of it previously given (fig. 84), fill up the valley of Chamonix with sea to the height of about 4000 feet above the village of Chamonix (3,425 feet above the sea), and, therefore, so that the perpetual snow line descended (in round numbers) to within about 1,000 feet from the sea level,† it will readily be seen that numerous glaciers would jut into the sea, resting upon and grating along the rocks forming their bases and sides, until the emersion in the water became such that they floated at their extremities, the transport of fallen fragments being continued in the manner that it now is, until the glacier reached the sea. Here the conditions for their further transport would be modified. Instead of terminal moraines, the blocks would be thrown into deep water, and those which now fall off the lateral moraines would be distributed at greater or less

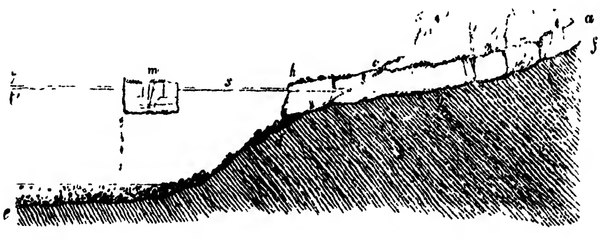
* In the Pyrenees, the conditions for the production of glaciers would appear to be such, that, where they occur, they are almost always found on the northern slopes of the mountains.

† Taking 8,500 feet above the sea as the snow line for the Alps, the altitude inferred by Professor Forbes.

distances from the new shores. Modifications would also arise from the increase or decrease of the mass of the glaciers, assuming the needful climatal changes. If we now add wave and breaker action, and tides, it will be seen that there would be a tendency to have the protruding portions of the glaciers, where they floated, broken away by the one and the other, more particularly when the glaciers were weakened by lines of crevasses, formed, as now, upon the land, before the protrusion seaward was effected. Great masses of ice would thus be borne away, supporting their moraines, gathered and transported outwards, as at present.

This imaginary case may be considered as realized, from the near approach of the perpetual snow line to the sea, with certain obvious modifications, in portions of the Arctic regions. Glaciers formed, necessarily, at minor altitudes above the sea, there descend to the shores in various situations, as, for example, in parts of Greenland and Spitzbergen,* even advancing beyond them, so that their extremities become separated and are borne away by tidal streams and sea-currents, the masses of ice often loaded with the fragments of rock detached from the cliffs and heights amid which the glaciers moved outwards, as in the Alps. Let *a*, *b*, *c*, *d*, and *e*, (fig. 90), represent the section of a portion of coast, partly beneath the level of the sea, and partly along a ravine or hollow, in which a glacier, *f*, *g*, *c*, *h*, finds its way outwards to the sea, *s*, so that at

Fig. 90.



h, it has a tendency to float at its extremity, from its relative specific gravity, as regards the sea, and it should be recollected

* With respect to the alternations of temperature productive of glaciers, it would appear that in these regions there is no want of the needful alternations of frost and thaw. In Greenland the heat of the days in the summer months is considerable, thawing the snow and ice, while the nights are commonly cold, with frosts. Even during the winter at Spitzbergen, when strong southerly winds prevail, thaws are known. The temperature of the warmest months at Spitzbergen is estimated at 34°·5, and the longest day lasts four months, the northern portion of these islands being within 10° of the North Pole.

that glacier ice would sink less deeply in sea than in fresh water. And let *t* be the level of ordinary high water in a tidal sea, and *t t'* the difference of level between high and low water. The ordinary glacier movements and their consequences would go on uninterruptedly, as in the Alps, allowing for the modifications due to an Arctic climate, from *f* to *g*, where the sea level cuts the coast and glacier; while from *g* towards *d*, a change in the polishing, grooving, and scratching of the rocky sides and bases would gradually be effected as the final floating of the ice removed its pressure from them. Still much of the polishing, grooving, and scratching would take place beneath the sea level, and the fragments which may have fallen between the glacier and its sides, or through crevasses of sufficient depth, while above the level of the sea, would be squeezed out beneath the ice under that level, accompanied by the finer detrital matter, derived in the manner above mentioned (p. 221), and borne away in mechanical suspension by glacier rivers. As the ice moved seawards, instead of the terminal moraine of an inland glacier, the blocks and fragments of rock of the lateral and central moraines, should there be such, would fall over into the sea, accumulating in different ways beneath it, according to the depth of water and configuration of the coast. It is assumed, for illustration, that at *d* such blocks do accumulate. With respect to the finer detritus, instead of being removed, amid dry land, by running waters, as in the Alps, its outward movements by such means would be checked at the sea level, *t*, with the difference due to the fall of tide *t'*. Its further course outwards would depend upon the specific gravity of the water loaded with this matter in mechanical suspension, and the general motion of the glacier. We have seen that the turbid waters of the Rhone readily sink beneath the clear water of the Lake of Geneva, spreading over the bottom (p. 44), and we should anticipate, from the melting of the glacier in the sea, and the consequent less specific gravity of the latter, that the turbid waters under notice, finding their way beneath Arctic glaciers in the usual manner above the sea level, would also be discharged outwards beneath the glacier. Taking all the circumstances into consideration, there would appear much probability of the finer detritus finding its way beneath the glacier into the sea, to be distributed over its bottom according to conditions, tidal streams and sea currents producing their usual effects. Along steep coasts, such as those of Greenland, where glaciers are so common, much mud may be thus distributed under the deep water which usually adjoins them, and into this mud glacier-borne,

fragments of rock, sometimes of considerable volume, would from time to time be discharged, so that the resulting mixture would be a clay without apparent stratification, amid which fragments of rocks, of very varied form and volume were dispersed.

The transport of fragments by glacier ice, the latter jutting into the sea, does not cease in the cold regions of the globe with the extension of the glacier itself. Not only is the glacier subject, at its seaward extremity, to the breaker action, which observers inform us undermines its base, and finally brings down huge fragments into the water, but also to the pressure of tidal streams or sea currents, and to the fracturing influence of the up-and-down motion produced by the rise and fall of tides in tidal seas. Some of the masses of ice thus broken off and and floated away, as at *m* (fig. 90), with any load of blocks and minor fragments of rock, which in the ordinary inland glaciers of temperate climates might be carried towards the terminal moraines, would contribute, as at *e* (fig. 90), by their melting, and during a long lapse of time, no small amount of blocks to be dispersed amid the clay or mud, even of deep waters, such as those in Baffin's Bay.

Greenland has been considered as a mass of land nearly covered by perpetual snows and interlaced with glaciers, many of the latter protruding beyond the ordinary coasts into the sea. Their seaward extremities are well known, after having been detached from their main masses, to be floated away, often bearing fragments of rock in and upon them, even to and beyond Newfoundland.* In the western and mountainous part of Spitzbergen, glaciers reach and protrude into the sea, exposing ice-cliffs from 100 to 400 feet in height. A little northward of Horn Sound, a great glacier is noticed as occupying 11 miles of the sea-coast, the highest portion

---

* The current from the northward bears a mass of ice with it to the southward along the east coast of Greenland; sea ice, as well as the glacier ice noticed above. The ice is described as sometimes extending across from Greenland to Iceland; polar bears being occasionally ice-borne to the latter, where they commit great havoc until destroyed. The accumulation of ice is stated to extend occasionally from 120 to 160 miles, seawards, around Cape Farewell. Its movement thence is described as northward to Queen Anne's Cape, passing afterwards to the western side of Davis's Strait, and from Cape Walsingham (Cumberland Island) along the American shore to Newfoundland.

Mr. Redfield (American Journal of Science, vol. xlviii., 1845) gives a valuable chart, illustrative of a paper, on the Drift Ice and Currents of the North Atlantic. Touching the general quantity of drift-ice, it is stated to vary considerably. "It is sometimes seen as early in the year as January, and seldom later than the month of August. From March to July is its most common season. It is found most frequently to the west of longitude 44°, and to the eastward of longitude 52°, but icebergs are sometimes met with as far eastward as longitude 40°, and in some rare cases even still further towards Europe."—p. 373.

rising in a cliff of 400 feet above the water. On the east coast of North-East Land great glaciers are also found.

M. Ch. Martins* mentions that the glaciers of Spitzbergen are commonly even and not much broken, and that the ice resembles that of the upper glaciers of Switzerland, pointing out that of Aletsch as a good illustration of the Spitzbergen glaciers. There are lateral, but no central moraines, the former proceeding with the glacier to the sea.† The cliffs of ice rising above the sea he estimates, as previous observers have done, as varying in height from 30 to 120 metres (98 to 393 English feet), and he states, that the seaward terminal portions of the glaciers rest on water. Respecting the height and slope of the Spitzbergen glaciers, he estimates the difference between the foot and the summit of a Bell Sound glacier at 1,150 feet, and its slope at 10°. The principal glacier of Bell Sound is also stated to be nearly horizontal, in consequence of its great length. M. Eugene Robert, who likewise visited Spitzbergen, remarks on the destruction of the ice by the breakers, and considers that where this is not effected, the masses of ice are very stationary. M. Durocher, who has also visited these lands, observes‡ that the glaciers do not there rise more than from 1,300 to 1,650 (English) feet above the sea; the snows above not taking the character of névé, being too much elevated above the needful conditions for its production.

The masses of ice detached from the land, floating about, and commonly known as icebergs, are sometimes of very considerable dimensions. The accompanying (fig. 91, p. 230) is a view of one seen by Sir Edward Parry§ in his first voyage, and is interesting, not only as showing the magnitude of this mass of ice (the far greater portion being concealed beneath the sea), but also as exhibiting something of its structure. It may be here observed,

* Observations sur les Glaciers du Spitzberg comparés à ceux de la Suisse et de la Norwége. Bull. de la Soc. Géol., vol. xi., 1840; Bibliothéque Universelle de Genève, 1840.

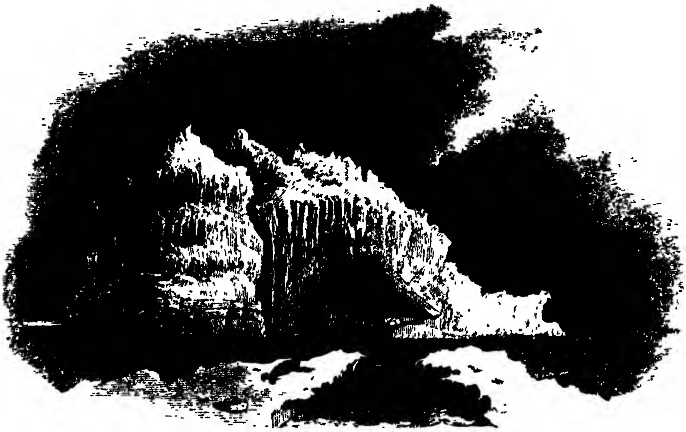
† Respecting the moraines of Spitzbergen, M. Martins observes that the bases of the nearly-vertical cliffs bounding the glaciers are covered with a mass of débris, fallen from the heights. Between these heights and the glacier there is sometimes a small valley or depression. The great glacier of Bell Sound is thus separated from its boundary heights. This glacier was merely stained with earth in its lateral portions. Those of Madalina Bay were covered with stones at their lower portions, occupying about an eighth part of their breadth. Not only were blocks seen in their upper surfaces, but also imbedded in the ice. M. Martins never saw them in the front of the glaciers bordering the sea.

‡ Mémoire sur la limite des neiges perpétuelles, sur les glaciers du Spitzberg comparés à ceux des Alpes—Partie de Géographie Physique du Voyage de la Récherche, 1845. Scoresby gives the height of the Horn Sound glacier as 1300 feet.

§ Reduced from a plate, in Parry's First Voyage, 4to edit.

that such masses of ice, remaining, as they are often known to do, stranded for a long time in some high latitude, might become covered with snows, marked by alternations of frosts and thaws, and even frozen rain, so that their upper parts may be in the condition of névé, thus covering over the remains of old moraines, resting on more ordinary glacier ice. Indeed, as respects the latter itself, in regions where the perpetual snow line closely approximates to and even cuts the level of the sea, we might expect the névé condition more and more to prevail, and it has been considered that icebergs are frequently of that character.

Fig. 91.



The northern icebergs may be regarded as the great carriers of rock fragments, often of a great size, from the lands where the bergs have been formed, as portions of glaciers, over a part of the Northern Atlantic, distributing them upon the bottom in various directions, and upon parts of it to which no other cause now contributes detritus.* Blocks and minor fragments may even be thus dropped upon bare rocks beneath, and upon every kind of inequality. Should a constant supply of block-bearing icebergs, regarding the subject generally, be thrown into any constant current, corresponding lines of deposit would result, assuming the melting of masses of ice, of various sizes, at different times and distances during their progress in such current; these lines having no reference to the form of the bottom, or to its modifications from any other deposits accumulated now, or at previous geological

* Mr. Couthouy mentions an iceberg, with apparently boulders upon it, as low down as latitude 36° 10′ N., and longitude 39° W. The same author states that he had often met with icebergs between the parallels of 36° and 42° N., in his voyages to and from America and Europe. American Journal of Science, vol. xliii., 1842.

times. Stranded near shores, or upon mud or sand-banks, these though somewhat deep in the sea, still catching their submerged portions, icebergs would tend much to disturb detrital deposits beneath them, particularly when moved by the waves produced during heavy gales of wind, as also by the rise and fall of tides. The heavy thumping of such huge masses, as some of these icebergs are, would cause great derangement of deposits effected tranquilly; and in many situations, blocks and fragments of rocks, with gravels, sands, and clays, would be irregularly mixed by the application of such force—singular intermixtures, and contortions of any previously bedded structure being produced. The icebergs which ground upon the Banks of Newfoundland can scarcely fail to produce much disturbance of the bottom, often adding to it great blocks and minor fragments of rocks, borne by them from more northern regions.*

As is well known, glaciers reaching the sea are not confined to the northern hemisphere,† they are also found in the antarctic regions. Sir James Ross mentions a great glacier, at Ætna Islet, South Shetland, as descending from a height of 1,200 feet into the ocean, where it presented a vertical cliff of 100 feet. Adjoining the termination of the glacier, Sir James found the largest aggregation of icebergs, evidently broken from it, he had ever seen collected together. Glaciers are also noticed by Sir James Ross as descending from the Admiralty Range (mountains 7,000 to 10,000 feet high) in Victoria Land, and projecting many miles into the sea, bare rocks in a few places inland breaking through the covering of ice. As in the arctic regions such glaciers may be expected to bring down with them those fragments of rock which

* Mr. Couthouy (American Journal of Science, vol. xliii., 1842, p. 155) mentions having seen (in September, 1822) a large iceberg aground on the eastern edge of the Great Bank of Newfoundland, and considered to be in about 720 feet water (120 fathoms), soundings three miles inside giving 630 feet (105 fathoms). A fresh wind from the eastward kept forcing it on the bank, the sea causing it to rock with a heavy grinding noise. On another occasion (August, 1827) he observed another iceberg aground upon the Great Bank, in between 480 and 540 feet water (80 to 90 fathoms). The huge mass rocked with the swell, going at the time, and even turned half over when struck by the breakers. The sea, for about a quarter of a mile around, was discoloured by mud worked up from beneath. Above water the iceberg was 50 to 70 feet high, and about 1,200 feet long. It suddenly fell over on its side, with much disturbance of the sea.

† Although glaciers are so common in Iceland, they do not appear actually to reach the sea. Those descending from the high Jökulls are noticed as separated from it by great moraines. Some of the glaciers are described as black in parts from the quantity of volcanic cinders and ashes with which they are covered. The sudden melting of snows and glaciers, from volcanic action in Iceland, is represented as producing great rushes of water, bearing large accumulations of volcani products outwards.

can fall upon them, to grate over the hard rocks on which they move, and to aid in contributing fine detritus to the adjacent sea-bottom, should the temperature be such that water could flow between the ice and the supporting rock. When we consider the volcanic character of so much of the great southern land as has been seen, we should expect that, as in Iceland, volcanic eruptions and the heating of the ground would occasionally produce the sudden melting of snows, and descent of the water, which could remain fluid sufficiently long to find its way to the sea. In this manner, not only the transport of ashes and cinders, and the larger volcanic substances vomited out of craters, may be moved to the lower ground, or into the sea, but also the fragments of rock which might have fallen upon snow or ice from any cliffs or steep places wherever atmospheric influences could detach them; not forgetting the effects of earthquakes (so common in great volcanic countries) upon the glaciers and snows, especially in localities where great avalanches could be produced.

Though from its general mode of occurrence, the great icy barrier of the antarctic regions might not, at first, appear any important agent in the transport of mineral matter, it has been found that, under certain conditions, portions of the ice, detached from it, may bear no inconsiderable amount of mud, sand, and rock fragments of various sizes into milder climates, depositing their loads over the bottom of the sea upon which they may be carried. This icy barrier presents a very singular appearance, stretching over a vast distance, with ice-cliffs rising from 150 to 200 feet above the sea, large fragments of them and minor pieces of ice floating in front of it, as shown in the annexed view* (fig. 92), representing a great detached mass in a long creek or bay in the barrier itself. From the relative specific gravity of the ice and sea-water, the former necessarily descends from beneath the level of the sea to a depth which might be estimated if the ice were of a uniform kind, with a known specific gravity. This is, however, far from being the case, for the layers of which it is composed, would appear to present somewhat the character of the névé of the higher parts of glaciers in temperate regions, being formed of alternations of snow, sleet, frozen mist and rain, with the refreezing of

* Taken from Captain Wilkes's "United States' Exploring Expedition," vol. ii. The vessel represented is the "Peacock," which had been driven against this great mass of ice. The view will at the same time afford an idea of the great barrier itself, which would be but an extension of a similar range of ice-cliffs. A long illustrative view of the great antarctic ice-barrier is given in Ross's "Voyage of Discovery and Research in the Antarctic Regions," vol. i. p. 232.

portions which in the summer months may be thawed at times by the influence of the sun.* As detached portions of this barrier were found by Sir James Ross aground, 60 miles from its main edge, and 200 miles from Victoria Land, in 1,560 feet of water, the ice was there at least of that thickness.

Fig. 92.

The depth of water obtained not far distant from the barrier† would show, as Sir James Ross has observed, that much of it must be upborne by the sea, and not rest on the sea-bottom, however the general mass may be held fast by adhering to land, or by reposing upon mud, sand, gravel, or solid rock, at minor depths. It will be obvious that the ice must be limited in depth by the temperature of the water to which it descends. We have seen (p. 96) that at the depth of 4,500 feet, the most dense water, with its temperature of 39°·5, appears to remain somewhat fixed in these regions, the waters of the upper parts of the sea necessarily varying in temperature according to the seasons. In January (1841), consequently in the summer of that portion of our globe, Sir James Ross found, about 12 or 14 miles from the barrier, a temperature of 33° at a depth of 900 feet, one which could not fail, widely spread beneath

* Sir James Ross describes gigantic icicles depending from the projecting parts of the ice-cliffs, proving that thaws sometimes took place. Notwithstanding that the time of the observation (February 9, 1841) corresponded, as respects season, with August in England, the temperature was at 12° (Fahr.) and did not rise above 14° at noon.

† Sir James Ross found (lat. 77° 56′ S., long. 190° 15′ E.) a depth of 1,980 feet (330 fathoms), within a quarter of a mile of the barrier, the bottom green mud. He also obtained 2,400 feet (400 fathoms) 12 or 14 miles off the icy barrier in another situation, about 100 miles from Victoria Land, the bottom being also a green mud, so soft that the sounding-lead descended into it 2 feet. "Voyage of Discovery and Research in the Southern and Antarctic Regions," vol. i.

as we might expect it to be, to act upon the lower part of the great mass of ice descending into the sea.*

Seeing that numerous and large masses of ice are annually detached from the great ice-barrier adjoining Victoria Land, and are floated off into milder regions, the question arises of whence the needful supply for this loss is obtained, assuming a certain general icy frontier to bound the barrier, and due allowance being made for the variation of seasons. The great thickness of the detached masses would lead us to consider that they were not portions formed on the outskirts of the main mass during certain seasons as additions to it, and were subsequently broken off, to be replaced by other additions; but rather that they were essential portions of the main mass, formed at the same time and in the same manner with it. Under this view there would be a motion outwards of this mass, sufficient to supply the annual waste of icebergs at the outer edge. Such a movement, though very slow, would yet produce a corresponding effect on the bottom of the sea over which this great mass of ice passed, grating over it, heavily pressing upon and scratching bare rocks and shingle beds, in the manner of a common glacier, though over a far wider area. Shingle beds, produced by some previous condition of land and sea, might thus, as well as any supporting rock, be scratched throughout, pebbles moved against pebbles, in lines of a general parallel character, over very extended areas.†

As the various layers of which the ice-barrier is formed indicate accumulations from atmospheric causes, unless the melting of the beds‡ beneath was equal to the deposit of snow, sleet, fog,§ and

* The temperature at 1,800 feet was 34°·2, at 900 feet 33°, at the surface 31°, and of the air 28°. In another situation (lat. 77° 49′ S. and long. 162° 36′ W.), and about one mile and a half from the barrier, Sir James Ross found the temperature of the bottom (green mud) at 1,740 feet (290 fathoms) to be 30°·8, only 2° lower, he observes, than would be obtained at a more considerable distance from the barrier, and showing the small influence of the mass of ice upon the sea adjoining it.

† Any outward motion of the great ice-barriers, however slow, by bringing portions of it forward which were based on rock, or shallow sea-bottoms, into depths where their bases could be melted, would also tend to keep those parts flattened which might otherwise have a large amount of snow or ice accumulated upon them, supposing such accumulation beyond the loss of evaporation and melting.

‡ As regards these layers, Captain Wilkes ("United States' Exploring Expedition," vol. ii.) observes, "that 80 different beds, on the average 2 feet thick, were counted in the large icebergs, detached from the main ice, and 30 in the smaller." Assuming similar beds beneath the sea level, the whole would constitute no small amount of ice and snow accumulated in horizontal layers and beds, in parts supported like beds of solid mineral matter by subjacent ground.

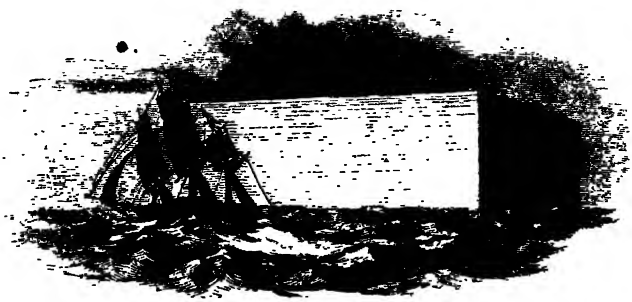
§ Respecting fog, Captain Wilkes remarks, "that it may make, when frozen, a marked addition to the ice accumulations, since he has known it frozen to the depth of a quarter of an inch upon the spars and rigging of the ships in a few hours."

rain (frozen upon its fall) above, there would be a continued increase of icy matter. The marked general uniformity in height of the ice-cliffs, and the tabular character of the surface of the barrier inwards,* would point to some cause having an extended and uniform action, so modifying any accumulation of the kind as to keep the mass at a general uniform thickness. The temperature of the sea at a fitting depth would appear sufficient to effect this, any addition from above to the general mass, so long as it plunged into water and did not rest on the sea-bottom, being compensated by the melting of the lower surface, pressed down by the increased accumulation above.

Captain Wilkes refers the formation of the ice in the first place to ordinary field ice, upon which layers from rain, snow, and even fog so accumulate, that the mass descending, takes the ground, part of it trending outwards into deeper water, and floating when conditions permit.†

Huge masses of this barrier, detached from it, float to more temperate regions, borne onwards by currents and prevalent winds. The accompanying sketch‡ (fig. 93) will afford an idea of the

Fig. 93.



tabular character of numerous icebergs before they have been much melted in more temperate climates, and also will show the stratified appearance noticed. Sir James Ross found many§ in about

* Where an opportunity occurred of seeing over the ice-cliff (about 50 feet high), Sir James Ross describes the mass as quite smooth in its upper part, and looking like "an immense plain of frosted silver."

† Wilkes, "United States' Exploring Expedition," vol. ii. Respecting that portion of the mass which reposes on the bottom beneath the level of the sea, we have also to consider the effect, for any value it may have, which may be due to terrestrial heat beneath, the ground protected from great atmospheric depressions of temperature by the mass of ice and snow above.

‡ Taken from Wilkes's "United States' Exploring Expedition," vol. ii.

§ 27th December, 1840. "Voyage of Discovery," &c. They extend often with a similar tabular character, according to particular seasons, more northerly. According to such seasons, also, the icebergs generally of the southern regions range to very different warmer latitudes. Upon returning from the antarctic regions in 1840, the different vessels of the United States' Exploring Expedition saw the last in 55° S.,

63° 30′ south, rising with tabular summits to the height of from 120 to 180 feet, several more than 2 miles in circumference. They were falling rapidly to pieces, and their course was marked by the portions of ice detached from them.

Respecting the mode in which icebergs are separated from the main mass of the ice barrier, and from the few he observed near it during the summer months, Sir James Ross infers that they are chiefly detached during the winter, the temperature of the sea and the air being then so different, whereas it more closely approximates during the summer. He points to the great cracks, some many miles in length, observed in the ice of arctic regions upon a sudden fall of 30° or 40° in the temperature, and more especially well seen in the great freshwater lakes, where the sudden rents are accompanied by loud reports. The unequal expansion of the ice exposed, on the surface, to 40° or 50° below zero (Fahrenheit), while beneath the temperature is 28° to 30° above it, could not, Sir James Ross infers, but produce the separation of large masses of ice. However little the action of the waves could affect a mass descending so low beneath the surface of the sea, we should expect that the influence of a rise and fall of tide would be felt, tending alternately to lift and depress much of it, especially at spring tides, so that supposing fissures formed, this very constant up and down movement would also tend to separate masses at the outer edge of the barrier.

While numerous icebergs are but the detached portions of the great ice barrier, which have not rested on a sea-bottom, and therefore transporting no mineral matter to milder regions, beyond any volcanic ashes or cinders discharged over the icy area, of which they may have formed a part, from such volcanic vents as Mount Erebus, and be interstratified with the layers of ice and snow,* others carry onwards no small amount of mud, sand, and rock fragments of different sizes. We have accounts of some covered with such detritus, blocks, so found, weighing several tons.† The detached portions of the glaciers, such as those de-

51° S., and 53° S. They were known to range so much northerly in 1832, that vessels bound round Cape Horn from the Pacific were obliged to put back to Chili for a time, in order to avoid them.

* Sir James Ross (Antarctic Voyage) mentions "that having observed new-formed ice off Victoria Land, covered with some colouring matter, a portion of the ice was melted and filtered, and an impalpable powder collected, considered as volcanic dust."

† Ross, "Voyage in the Antarctic Regions," vol. i. p. 173. Mr. Couthouy observed masses of rock embedded in an iceberg seen in lat. 53° 20′ S., long. 104° 50′ W., 1,450 miles from Tierra del Fuego, and 1,000 miles from St. Peter's and Alexander's Islands, whence he supposes the ice to have drifted. One of the rock masses seemed to show

scending from the Admiralty range, would be expected to transport the fragments which could fall upon them, as in the arctic regions. It would appear that, in addition to whatever may be thus carried, large icebergs which have rested upon the sea-bottom are often capsized, so that the mud, sand, and pieces of rock adhering to them beneath are suddenly upturned, a very great change in the relative position of such detritus being in this manner quickly produced. Sir James Ross mentions one suddenly capsized off Victoria Land, bringing up a portion of the bottom 100 feet above the surface of the sea, so that it was, for the moment, supposed to be an island not previously seen.* In this manner detritus may not only be transported directly from the land upon detached portions of glaciers, but also the mud, sand, and stones of a sea-bottom be uplifted several hundred feet, and carried great distances into milder climates.† A somewhat constant supply and a general course of the floating ice, from currents and prevalent winds, would cause a vast quantity of the detritus, thus obtained and floated away, to be distributed over the sea-bottom; mud, sand, and fragments of varied sizes mingled together. Though the finer matter would take longer to sink through the sea,‡ and so far become strewed over the bottom more widely and in a more even form, enveloping various inequalities that may occur (as well covering the tops as the sides, if not too steep, of submarine hills), the larger fragments would fall more irregularly upon and into the finer sediment. Submarine hill-tops would be as much covered by them as any depressions, and they would often be plunged into

---

a face of about 20 square feet. When within half a mile of this iceberg, the temperature of the air was 35°, and of the water 34°. The water to leeward of the ice was 7° colder than 4½ miles to windward of the berg.—"American Journal of Science." vol. xliii., 1842.

* "Antarctic Voyage," vol. i. p. 196.

† Captain Wilkes ("United States' Exploring Expedition") considered that he landed upon an upturned iceberg, part of the icy barrier weathered by storms, about eight miles from the main land, in latitude 65° 59′ 40″ S. Upon it were boulders, gravel, sand, and mud or clay. The larger specimens were of basalt and red sandstone. One piece of rock was estimated at 5 to 6 feet in diameter. The stones were cemented by very compact ice, thus forming an icy conglomerate.

As regards the distances to which the icebergs from the southern ice are carried, Captain Wilkes infers that they are conveyed westward the first season by the south-east winds, about 70 miles north of the barrier, being the second season driven northwards until they reach 60° S., after which they rapidly move more northward and disappear. Sir James Ross mentions a tabular iceberg, rising 130 feet above the sea, and three-quarters of a mile in circumference, in about 58° 36′ S.

‡ Sir James Ross ("Antarctic Voyage") considers the bottom as usually to be found in the Antarctic Ocean at 12,000 feet. Inequalities to a considerable amount also exist. No bottom was obtained by a line of 24,000 feet in latitude 68° 38′ S., and longitude 12° 49′ W.

mud, in the same manner as the sounding-lead above mentioned (p. 233), and which descended two feet into the fine green mud beneath 2,400 feet of sea, at a distance of 100 miles from Victoria Land. This fine mud would not appear an uncommon sea-bottom off Victoria Land,* and as icebergs discoloured by mud seem not unfrequent in these southern latitudes, such mud may be widely

* This mud seems, from the soundings obtained by Sir James Ross ("Antarctic Voyage"), to be common for about 400 miles along the great icy barrier near Victoria Land. It has been noticed previously (p. 233) that a detached portion of this barrier was found aground upon it, beneath 1,560 feet of water, 200 miles from that land. Respecting its composition, those minute bodies the *Diatomaceæ*, which were considered by Ehrenberg and many naturalists as infusorial animals, and by others as vegetables, and which seem now, especially from the researches of Mr. Thwaites, to be admitted by Dr. Hooker, Dr. Harvey, and other highly-qualified persons as the latter, would appear to form no inconsiderable portion of it. At the same time, as no rivers of Victoria Land bear out fine sediment, and great volcanos are there in activity, we may look to the distribution of ashes and cinders vomited forth from the latter as adding such products from time to time to this mud.

"The water and the ice of the South Polar ocean," observes Dr. Hooker ("Flora Antarctica," vol. ii. p. 503), "are alike found to abound with microscopic vegetables belonging to this order (Diatomaceæ). Though much too small to be discerned with the naked eye, they occurred in such countless myriads as to stain the berg and pack ice wherever they were washed by the swell of the sea; and when enclosed on the congealing surface of the water they imparted to the brash and pancake ice a pale ochreous colour. In the open ocean northward of the frozen zone, this order, though no doubt almost universally present, generally eludes the search of the naturalist, except when its species are congregated amongst that mucous scum which is sometimes seen floating on the waves, and of whose real nature we are ignorant, or when the coloured contents of the marine animals which feed on these *Algæ* are examined. To the south, however, of the belt of ice which encircles the globe, between the parallels of 50° and 70° S., and in the waters comprised between that belt and the highest latitude ever attained by man, this vegetable is very conspicuous, from the contrast between its colour and the white snow and ice in which it is embedded, insomuch that, in the eightieth degree, all the surface ice carried along by the currents, the sides of every berg, and the base of the great Victoria Barrier itself, wi hin reach of the swells, are tinged brown as if the polar waters were charged with oxide of iron.

"As the majority of these plants consist of very simple vegetable cells, enclosed in indestructible silex (as other *Algæ* are in carbonate of lime), it is obvious that the death and decomposition of such multitudes must form sedimentary deposits, proportionate in their extent to the length and exposure of the coast against which they are washed, in thickness to the power of such agents as the winds, currents and sea, which sweep them more energetically to certain positions, and in purity to the depth of the water and nature of the bottom. Hence we detected their remains along every ice-bound shore, in the depths of the adjacent ocean, between 80 and 400 fathoms. Off Victoria Barrier the bottom of the ocean was covered with a stratum of pure white or green mud, composed principally of the siliceous cells of *Diatomaceæ*; these on being put into water rendered it cloudy, like milk, and took many hours to subside. In the very deep water off Victoria and Graham's Land this mud was particularly pure and fine; but towards the shallower shores there existed a greater or less admixture of disintegrated rocks and sand, so that the organic compounds of the bottom frequently bore but a small proportion to the inorganic."

Respecting the distribution of the *Diatomaceæ*, Dr. Hooker remarks (Ibid. p. 505) that many species are found from pole to pole, "while these or others are preserved in a fossil state in strata of great antiquity. There is also probably no latitude between that of Spitzbergen and Victoria Land, where some of the species of either country do not exist: Iceland, Britain, the Mediterranean Sea, North and South

distributed and be irregularly supplied with sand, stones, and large fragments of rock, as the icebergs melt away and drop their loads of mineral substances.*

Captain Cook long since (1777) made known the fact that, at the mountainous island of South Georgia, included between latitude 53° 57′ and 54° 57′ S., glaciers descended into the sea, detached masses from which floated outwards, to be distributed by ocean currents and prevalent winds, in given directions. The following view of Possession Bay† (latitude 54° 5′ S.), in that island presents us with a glacier reaching the sea, the depth of which was more considerable than that of an ordinary sounding line (204 feet) employed at the time. Captain Cook says, "The head of the bay, as well as two places on each side, was terminated

Fig. 94.

America, and the South Sea Islands, all possess Antarctic *Diatomaceæ*. The siliceous coats of species only known living in the waters of the South Polar ocean have, during past ages, contributed to the formation of rocks, and thus they outlive several successive creations of organized beings. The phonolite stones of the Rhine and the tripoli stone contain species identical with what are now contributing to form a sedimentary deposit (and perhaps at some future period a bed of rock), extending in one continuous stratum for 400 measured miles. I allude to the shores of the Victoria Barrier, along whose coast the soundings examined were invariably charged with diatomaceous remains, constituting a bank which stretches 200 miles north from the base of Victoria Barrier, while the average depth of water above it is 300 fathoms, or 1,800 feet."

* As respects sand intermingled with ice and carried away, Captain Wilkes mentions ("United States' Exploring Expedition") a floating mass, composed of alternate layers of snow and ice, the former mixed with sand. Upon this pieces of granite and red clay were also found.

† Taken from the plate, vol. ii., p. 213, of Cook's "Voyage to the South Pole," 4to, 1777.

by perpendicular ice-cliffs of considerable height. Pieces were continually breaking off, and floating out to sea; and a great fall happened while we were in the bay (January 17, 1775), which made a noise like cannon." He also calls attention to the bottom of the bays generally in this land being filled by glaciers, supplying an abundance of icebergs; and it is easy to infer that, from amid the mountain cliffs among which these glaciers find their way to the coast, many a fragment of rock may be ice-borne, and deposited at the bottom of the sea, remote from South Georgia. Not a stream or a river could be seen throughout the whole coast explored, though it was visited in the summer of that region. Captain Cook also mentions bays full of glaciers, descending from the heights of Sandwich Land, discovered by him upon leaving South Georgia, on the south-east of that island.*

Quitting the far southern land and remote islands, the climate is such in Tierra del Fuego, although comprised between latitude 52° 30′ and 56° S. (a range corresponding in the northern hemisphere with the position and distance between Birmingham and Edinburgh), that the line of perpetual snow occurs, according to Captain King, at between 3,500 and 4,000 feet above the sea in the Straits of Magellan, and that glaciers descend into the sea.† Mr. Darwin states that on the north side of the Beagle Channel (a remarkable strait, running east and west across the southern part of Tierra del Fuego) the mountains are covered with perpetual snow, whence, in many places, magnificent glaciers descend to the water's edge, fragments falling from them into the sea, and floating about as miniature icebergs.‡ He remarks that glaciers occur at the head of the sounds along the whole western coast of the southern

* Cook's "Voyage to the South Pole," vol. ii., p. 224. He remarks also upon the flat surfaces, and even heights, of the icebergs in that region, some two or three miles in circumference, reminding us of the character of those off the great ice barrier near Victoria Land.

† Mr. Darwin gives the following table of the climate of Port Famine, Straits of Magellan, and of Dublin:—

	Latitude.	Summer Temperature.	Winter Temperature.	Difference.	Mean of Summer and Winter.
	° ′	°	°	°	°
Dublin	53 21 N.	59·54	39·2	20·34	49·37
Port Famine	53 38 S.	50·	33·08	16·92	41·54
Difference . . .	0 17	9·54	6·12	3·42	7·83

‡ Darwin, "Voyage of Adventure and Beagle," vol. iii., p. 243.

part of South America.* It would appear that as far north as latitude 48° 30′ S. glaciers advance into the sea. Eyre's Sound is terminated by glaciers descending from the range of the Sierra Nevada on the east. Mr. Bynoe saw numerous detached masses of ice floating about, 20 miles from the head of the sound; and upon one, drifting outwards, found an angular block of granite, described as a cube of nearly two feet, partly imbedded in it, the ice thawed around.† Mr. Darwin directs attention to the occurrence of a glacier at the level of the sea, even in latitude 46° 40′ S., in the Gulf of Penas, reaching to the head of Kelly Harbour, pointing out that thus "glaciers here descend to the sea within less than nine degrees of latitude from where palms grow, less than two and a half from arborescent grasses; and, looking to the westward, in the same hemisphere, less than two from orchideous parasites, and within a single degree of tree ferns."‡

The transport of mineral matter by floating ice is not limited to portions of glaciers, broken off where they have protruded into the sea, or to masses detached from great continuous ranges of ice, such as the barrier off Victoria Land. Rivers, in regions where the temperature descends sufficiently low, remove no small portion of such matter by means of ice down their courses, and coast ice distributes no inconsiderable amount of it in various directions. As regards the mode in which detritus may be conveyed by rivers, it may often be studied in our brooks and streams, when a sudden thaw suddenly fills them with water, lifting away ice which may bind gravel, sand, or pieces of frozen mud together, by their sides or in shallow places. According to the relative specific gravities of the detached portions of ice, stones, sand, and mud, will they be seen to move, some larger pebble, perhaps deeply set in its support of ice, trailing along, and leaving the mark of its passage on the bottom. Other portions will float more freely onwards, some acquiring rotatory motion, and, by grinding against each other,

* Darwin, "Voyage of Adventure and Beagle," vol. iii., p. 282. Mr. Darwin observes (p. 283), "In the Canal of the Mountains no less than nine (glaciers) descend from a mountain, the whole side of which, according to the chart, is covered with a glacier of the extraordinary length of 21 miles, and with an average breadth of 1½ mile. It must not be supposed that the glacier merely ascends some valley for the 21 miles, but it extends apparently at the same height for that length, parallel to the sound, and here and there sends down an arm to the sea-coast. There are other glaciers having a similar structure and position, with a length of 10 or 15 miles (Tierra del Fuego).

† "Voyage of Beagle," vol. iii., p. 283. Mr. Darwin calls attention to this sound being in a latitude corresponding, in the north, with that of Paris, and also to an "Iceberg Sound," as given in the charts still further north.

‡ Ibid., p. 285.

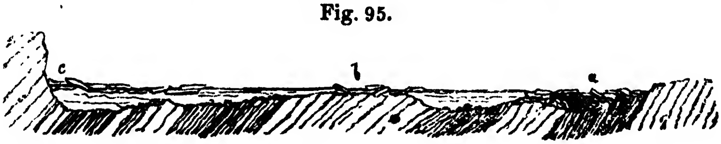
parting with some parts of their load, especially the heaviest, while here and there they become jammed in the narrower parts of the stream, and stranded upon shoals, there remaining, in great part, until, the thaw proceeding, the ice melts, and the detrital matter is dealt with by the stream in the usual manner.*

The transport of mineral matter which may often and easily be seen in this minor manner, under the fitting conditions, is but carried out upon a larger scale in many great rivers, where the relative magnitude of the effects produced more engages our attention, especially when those objects to which we attach interest are endangered or sustain injury. In the regions where ice is common upon great rivers during part of the year, and that part of the year the time when the water supply is the least, and the river level the lowest, the fragments of rock, pebbles, sand, and mud of the sides, and shoal grounds become, as it were, a piece of the main sheet of ice, should it extend entirely over the river, or of such portions of one as may exist. These are ready to be broken off, lifted, and borne down the stream as the waters of the river rise before any general increase of temperature melts the ice upon the banks, shoals, or general surface of the river. It will be obvious that the transport of detritus will depend upon circumstances, as in the little brooks, and that while some portions are carried long distances, others will be left in various situations; sometimes fragments of rock being carried to, and accumulated in, situations where the ordinary force of the river cannot readily dislodge them, and indeed sometimes be altogether insufficient for the purpose. We have various accounts of detritus so borne downwards in rivers by means of ice. In the St. Lawrence there would appear to be good opportunities of studying the transport of mineral matter on the large scale. Captain Bayfield

* It is while studying the effects of ice in the brooks and minor streams that an observer may sometimes see the formation of ice at the bottom. M. Arago, whose attention this subject has engaged, remarks respecting it ("Annuaire du Bureau des Longitudes pour 1833," p. 244), that the movement of these running waters mixes those of different temperatures and densities, so that when the whole is at the freezing point, the pebbles and other substances at the bottom of the brook constitute so many projections, as in a saline solution, and thus ice is formed upon them. The ice thus produced is spongy, from the crossing and confused grouping of its crystals, the movement of the water preventing an uniform arrangement of parts. The ice accumulates, and gradually envelopes numerous pebbles and other substances, and will rise to the surface with its mineral load if the general specific gravity of the whole will permit. M. Leclercq has observed ("Mémoires Couronnés par l'Académie de Bruxelles," tom. xiii. 1845) that the ice is first formed upon the face of the pebbles or other objects opposed to the current of water, and that, although a rapid flow of water contributes to the first production of the ice, the increase of ice is in proportion as the movement of the water is moderate, the extreme cold considerable, and the sky clear.

has pointed out that there, where the temperature in winter sometimes descends 30° below zero (Fahr.), large boulders are entangled in the ice, and carried considerable distances upon the surface of the water in the spring. Shoals are thickly strewed with them.* Conditions being favourable for keeping blocks and fragments of rock in the lower part of the river ice, thus carried onwards, and indeed often driven forwards rapidly, wherever the general masses grated upon any bottom, over which they could be forced by the volume of water behind (and heavy piles of ice sometimes accumulate, obstructing the free flow of the waters), much scratching and furrowing would be expected, according to the relative hardness of the rocks passed over and of the ice-borne fragments, to the pressure of the mass of ice and detritus, and to the velocity with which that mass may be driven upon the rocky ledge or shoal. Fragments of rock, set in the ice, and grating against vertical cliffs rising from comparatively deep water, such as frequently occur on the bends of rivers, would also horizontally scratch and abrade the rocks, according to their relative hardness, the ordinary river action not removing these marks, though they may become obliterated by atmospheric influences at lower states of the river, especially where the cliff-rocks were composed of somewhat incoherent materials. Thus while some ice-supported boulders and fragments of rocks were grooving and furrowing the horizontal surface of a ledge of rocks at *b* (fig. 95), and others, encased in ice, were borne down the river at the same time, scratching and wearing away the vertical cliff at *c*, another collection might be leaving permanent traces of its passage upon previously ice-borne boulders, accumulated from local causes at *a*.

Fig. 95.



It is interesting to consider that by such means large rounded portions of rock, with minor pebbles, may thus be borne towards the Gulf of St. Lawrence, and be thrown down, after being scratched in their passage over hard ledges of rock, or over boulders in shallow water, in situations where such marks would not be removed by any attrition to which they would be exposed under existing circumstances, there accumulating with finer detritus, even mud deposited from water in which it had been held in ordinary

* Bayfield, "Proceedings of Geolog. Soc. of London" (1836), vol. ii., p. 223.

mechanical suspension. Thus the scratching of the ledges of solid rock and heavy stranded boulders in shallow situations might be accomplished, and the boulders and pebbles by which this was effected be themselves often also scratched, carried onwards under favourable circumstances, and be deposited, with these marks still upon them, amid fine sediment in depths beyond the reach of wave or breaker action for the attrition necessary to remove such scratches.

The great rivers of Northern Europe, Asia, and America delivering themselves into the Arctic Sea, flowing as they do from milder into colder climates, present us with the conditions for the formation of ice sooner, and its continuance later at their embouchures than towards their origin. The effects produced are especially interesting, inasmuch as when, from the melting of the snows and ice on the southward, floods are produced, these meet with the obstruction of the ice towards the mouths of rivers. In consequence, it not unfrequently occurs that the resistance of the ice being suddenly overcome, it is violently upheaved and broken, and in parts thrown aside, with any masses, or minor fragments of rocks attached to it. Sir Roderick Murchison has pointed out the banks of rock-fragments thus produced on the sides of rivers in Russia, and especially notices the fluviatile ridges of angular blocks towards the mouth of the Dwina. White carboniferous limestone there occurs (about 110 versts from Archangel), and the waters of the river entering amid its chinks and joints, separates them when frozen, so that subsequently they are entangled in the ice adjoining the banks, and are thus carried with it.* By the sudden rise of waters thus caused, many a block of rock must be borne over low ground, stranded on shoal water, or be occasionally carried seawards, and thrown down amid fine sediment, the conditions for the transport of which outwards would be increased during these sudden discharges of water. The crashing and jamming together of the broken masses of ice would be highly favourable to the scratching and scoring of blocks and fragments of rocks entangled among them, and such blocks and fragments may also be often transported to situations where, under existing circumstances, the markings thus produced would not be obliterated.

---

* Murchison, "Geology of Russia in Europe and the Ural Mountains," vol. i., p. 567. He quotes M. Böhtlingk as noticing large granitic boulders, weighing several tons, entangled in the branches of pine trees, 30 or 40 feet above the level of the streams. Speaking of blocks of rock ice-borne down rivers, Sir Roderick Murchison, after noticing their modes of transport and deposit, remarks, that old drift from the north may thus be brought back to the northward by the rivers, p. 565.

When we consider the state of sea-coasts in regions where the temperature falls sufficiently low during a part of the year that ice is formed upon them, entering amid the substances of which they are composed, and binding blocks of rock, shingles, sand, and even mud, with the remains of any marine animals there occurring, into one solid mass, we see that when the warmer season in such regions comes round, mineral matter may be readily removed from one place to another upon the breaking up of the coast ice.

Upon the breaking up of this coast ice, which sometimes rests on shallow ground, and at others covers deep water, we should expect much grinding of the masses on the shore, scratching and grooving the sides of cliffs and shallow rocky bottoms, when shingles or other fragments of rock are frozen into the ice, so as to be brought into contact with the one or the other.* The force employed would appear to be often very considerable, great sheets of ice being set in motion, and being driven with tremendous crashes against the land, so as not only to act upon shore ice, in which rock fragments and shingles may be embedded, thus pressing them heavily against bare rocks, but also forcing beaches before them, grinding the pebbles and boulders against each other, and upon exposed rocks, by which both may be scored and marked. In this manner friction marks may be produced, which in some situations may not be very readily removed by the ordinary rounding and smoothing of breaker action.

When an observer studies the maps and charts which we as yet possess of the northern seas of America, Europe, and Asia, he will find enough to show him that portions of beaches may readily be removed upon the breaking up of ice from the coasts, and be transported to other situations, where, upon the melting of that ice, they may be thrown down in depths amid any fine detritus there

* M. Weibye, of Kragero, is quoted by M. Frapolli ("Bulletin de la Société Géologique de France," 1847), as inferring, respecting the marks left by the block-and-shingle-bearing ice of the Scandinavian coasts, that on those bordering the sea in the Bradsbergsamt, "the scratches and furrows on horizontal, or nearly horizontal surfaces, take a direction always perpendicular to the general line of coast in open bays, and always parallel to the range of the channels in narrow fiords, that the horizontality or the greater or less inclination of the scratches on the inclined or vertical surfaces depends on the relief of the coasts of the locality, and always corresponds with this relief and with the action of the different winds." M. Frapolli himself also calls attention to the effects of coast ice armed with blocks and pebbles of rock, driven about in numerous fragments by the storms of winter and spring, and grinding against the cliffs of Scandinavia, polishing and scratching the rocks according to their surfaces and position, the cliffs scratched in horizontal lines along the fiords and in other simillar positions.

accumulating. Should any of their component pebbles or fragments of rock have been so acted upon as to be scratched before they were thrown down, they would retain those marks amid the fine deposits in such depths. As ice adheres to coasts in many localities during winter, upon which, from the ordinary action of the sea on shores, breakers throw whole and broken shells of molluscs and other marine animal remains during the summer, these remains would be liable to be entangled in portions of beach removed by the ice, and be scattered over various depths of water, in the same manner as the transported mineral matter, and thus the remains of littoral molluscs, often in fragments, may be dispersed amid a mixture of mud, and ice-borne blocks, and fragments of rock accumulating in deep water.

In tidal seas account has to be taken of the movement of ice in estuaries, and in those long deep loughs or arms of the sea, in Norway termed *fiords,** up and down which the flood and ebb tides are felt according to circumstances. Coast ice, borne backwards and forwards by the tide, and having pebbles and fragments of rock so set in it that they can grind upon or against bare rocks, spread horizontally or rising vertically, or nearly so, in the estuaries and fiords, could scarcely fail to become an instrument of importance in the scratching and grooving of such bare rocks, these markings being also, especially in the case of the cliffs, not easily removable. This action continuing through many successive ages, certain kinds of rocks might, in favourable localities, retain marked scratches and grooves thus produced, independently of the influence of winds driving the fractured coast ice about against lines of coast, upon the breaking up of such ice. Fragments of ice and any mineral matter they may sustain are thus piled up at the bottom of bays or in shoal water, a combination of a heavy on-shore gale of wind and a spring tide leaving many a fragment of rock in a situation whence it could not readily be removed under ordinary circumstances.

No small amount of rounded boulders and pebbles of various sizes may thus become strewed near coasts, or be mingled beneath deep water with the angular fragments which have either been transported by icebergs, broken off the terminal portions of glaciers,

* The channels which divide Tierra del Fuego into its many islands, and the Straits of Magellan separating it from the mainland of America, with the very numerous indentations and channels found between the east entrance of the Straits of Magellan and the Gulf of Penas, and into which glaciers often descend, and ice floats about, would appear to be frequently very deep and steep-sided. In mid-channel, eastward of Cape Forward, Captain King found no bottom in the Straits of Magellan with a line of 1,536 feet.

or which may have fallen from cliffs upon coast ice, with the addition even of the remains of littoral or shallow-water molluscs, or of other marine animals, such as the bones of fish, whales, and seals carried off by the coast ice. A good example of the removal of a block of rock by coast ice, so far from the polar regions as Denmark, is mentioned by Dr. Forchhammer, who states that one, about 4 to 5 tons in weight, and resting on the shore, was encased in coast ice during the winter of 1844, and carried out to sea with the ice in the following spring, leaving, as it moved seaward, a deep furrow in the sandy clay of the shore, not quite obliterated six months afterwards.*

As modifying the accumulations which may be formed on the bottoms of seas liable, from time to time, and, sometimes, as a whole, periodically, to sustain icebergs grounded upon them, the observer has to bear in mind that not only may the icebergs, by being forced against banks, jumble together, and singularly mingle beds of clay and sand, even occasionally adding transported fragments to the disturbed mass, but also act as rocks round and amid which streams of tide, or sea-currents, may become for the time modified. We should expect this to be most experienced in the regions where, from the general intensity of the cold, the icebergs could the longest remain. Sir James Ross mentions that the streams of tide were so strong amid grounded icebergs at the South Shetlands, that eddies were produced behind them,† so that, as far as such streams were concerned, they acted as rocks. Navigators have observed icebergs sufficiently long aground in some situations, that even mineral matter might be accumulated at their bases in favourable situations, while streams of tide may run so strongly between others, that channels might be cut by them in bottoms sufficiently yielding, and at depths where the friction of these streams could be experienced. Much modification of sea-bottoms might be thus produced by grounded icebergs, not forgetting those seasons of the year when many become joined together by ordinary sea-ice, con-

* Forchhammer, "Bulletin de la Société Géologique de France," 1848. He observes, respecting the transport of blocks and pebbles on the coast of Denmark by coast ice, that although the latter envelopes the blocks and pebbles on the shore, to enable these to be borne away, it is necessary that the thaw or rupture of the ice should coincide with a rise of the waters. Respecting blocks and fragments of rock borne out by the ice from the Baltic, by means of the current setting through the Kattegat in the spring, Dr. Forchhammer mentions that, in 1844, a diver found the remains of an English cutter, blown up during the bombardment of Copenhagen in 1807, covered by blocks, some of which measured from six to eight cubic feet. The same diver affirmed that all the wrecks he had visited in the roadstead of Copenhagen were more or less covered by rock fragments.

† Ross, "Antarctic Voyage."

stituting part of a mass to be dealt with on the large scale, when such ice is broken up. However firm the grounded icebergs may, like so many anchors, often tend to hold the main mass, it is not difficult to conceive that conditions arise by which many are dragged, cutting and ploughing up the sea-bottoms in their courses.

Ice thus transports portions of rocks, either in the shape of glaciers, descending under the needful conditions in various extra-tropical regions, as floating ice down rivers, as coast ice, as fragments of glaciers descending into the sea, or as masses which, having been aground, capsize, and bring up a portion of the bottom on which they previously rested. Huge fragments of rock are by these means moved to distances from their parent masses, of which no other known power, now in force on the surface of our globe, appears capable. It has been seen that glaciers increase and decrease according to the variations of the climates under which they are formed. What the amount of that increase and decrease may be under the conditions now existing, and where glaciers have been noticed, seems not well ascertained, though the differences in their volume and extent would appear to have been greater than was once supposed. Be that as it may, they distribute rock fragments outwards from mountain regions, these generally angular, unless ground between the glacier sides and bottom, the larger blocks and fragments remaining where the glaciers left them, while minor portions and finely-comminuted mineral matter are thrown into the torrents and rivers, to be disposed of by them according to their powers. River ice may carry detritus entangled in it, distributing the mineral matter over areas corresponding with their courses, and which may be sufficiently flooded by them, transporting many a block and fragment which the power of the stream could not otherwise have moved. With the exception of rock fragments, which may have fallen from cliffs overhanging the rivers and not afterwards have been rounded, which may have been broken up from the sides in the manner previously noticed (p. 244), or which may have been left by some prior geological condition of the area, we should expect much of the detritus borne down by river-ice to be composed of the ordinary pebbles, sand, and mud of river courses.

The sea deals with any ice-borne detritus received from rivers, or from the coasts, according as it is tideless or tidal, and as the portions into which these are carried may be in movement as sea and ocean currents, or the ice be acted on by the wind. Looking at the northern regions, where rivers of sufficient importance discharge themselves, carrying ice outwards, and coast ice is

common, it may be anticipated that much coast shingle, with rounded river pebbles, lumps of the frozen mud, and sands of estuaries, the occasional remains of marine animals, and now and then those of terrestrial animals, suddenly swept outwards by the river floods, would be strewed about upon the sea-bottom. Many a bone of elephants, rhinoceroses, and other animals, imbedded in the mud, sand, and gravel, of these regions, may also, after having been washed out of the beds which contained them, be ice-borne into the sea, and be mingled with remains of existing animals. To these may be added angular fragments carried out by the ice of rivers, or borne by coast ice from beneath cliffs whence such fragments have fallen upon it, independently of those carried into parts of the same seas by icebergs detached from the terminal part of glaciers.

Although the arctic seas are so shut in by the lands of America and Asia, a comparatively small opening (Behring's Strait) only occurring between them, a space sufficiently wide exists between America and Europe, notwithstanding the interruption presented by Iceland, to permit the escape outwards of a certain portion of ice. We have seen that over the bottom of part of the North Atlantic blocks and fragments of rocks, with minor detritus, are now being strewed, without reference to its inequalities. In the antarctic seas very different conditions present themselves. Great rivers bearing ice-borne blocks and fragments of rocks, with minor detritus, are not found. The land, now commonly supposed to occupy so large an area in the South Polar regions, supports little else than water in its solid form, and the coast, for the most part, seems so encased by huge icy barriers, that common coast ice would there appear considerably limited, as compared with the arctic regions, in its power to carry off rounded boulders and shingles. Such glaciers as reach the sea, transporting fragments from the inland cliffs amid which they may move, would appear the principal agents in carrying mineral matter directly from the land, allowing for a portion transported by coast ice. The ice aground off Victoria Land would nevertheless appear to have the power of transporting much detritus when broken up into icebergs and upset, strewing blocks and minor fragments, sand and mud, over a part of the Southern Pacific. The South Shetlands, South Orkneys, South Georgia, Sandwich Land, and the lands more or less encased with ice between the South Shetlands and Victoria Land doubtless also contribute, by means of glaciers, coast ice, and probably also, as capsized grounded ice, blocks and frag-

ments of rock (some rounded), sand and mud, to the bottom of the Southern Atlantic, and the ocean southward of Africa and Australia. The southern portion of America adds its glacier-borne fragments, and thus, both on the north and on the south, portions of rocks, formed in the colder, are ice-borne, and left beneath the seas of the more temperate, regions of the earth.

CHAPTER XIV.

INFLUENCE OF A GENERAL INCREASE OF COLD.—MODIFICATIONS OF TEMPERATURE FROM CHANGES IN THE DISTRIBUTION OF LAND AND SEA.—ERRATIC BLOCKS.—EFFECTS OF GRADUAL RISE OF THE SEA BOTTOM STREWED WITH ICE-TRANSPORTED DETRITUS.—EFFECTS OF A SUPPOSED DEPRESSION OF THE BRITISH ISLANDS.—INCREASE OF ALPINE GLACIERS.—TRANSPORT OF ERRATIC BLOCKS BY GLACIERS.—FORMER EXISTENCE OF GLACIERS IN BRITAIN.—ELEVATION OF BOULDERS BY COAST ICE DURING SUBMERGENCE OF LAND.—ERRATIC BLOCKS OF THE ALPS.—ERRATIC BLOCKS OF NORTHERN EUROPE.—ERRATIC BLOCKS OF AMERICA.

THE geological effects now due to ice being as previously represented, it becomes desirable to consider those which would probably arise either from a general diminution of temperature on the surface of the globe, or from partial changes of that temperature. With respect to the first we have to look to some general cause common to the whole globe. Whatever the conditions for the distribution of temperature may have formerly been, we see that the influence of the sun now causes the heat of the tropics, and the different exposure of the polar parts of the earth's surface to it, the great variations of seasons there experienced. Any changes of sufficient importance, therefore, in the influence of the sun, which should produce a corresponding change on the face of the earth, so that the line of perpetual snow, as it is termed, should descend lower towards the sea in the equatorial, and cut its level at less high latitudes in the polar regions, would materially alter the climates of many parts of the world. Geological effects due to ice would be more widely spread than they now are, and the equatorial space within which ice-transported masses of rock and other detritus cannot be borne, would be more limited. Glaciers, where they could be formed, would not only become more extended than they now are in certain mountainous regions, but ranges of mountains, amid which they do not at present occur, the line of

perpetual snow not descending sufficiently low, would contain them; so that, in the one case, mineral matter would be distributed by them over a wider area; and in the other, over districts where no transport of the kind exists at the present time. Fragments angular, subangular, and rounded, would be distributed by river-ice and coast-ice, where none such are now formed, and sea-bottoms would then be strewed over by them, where, at present, nothing of the kind is carried. Animal and vegetable life would be adjusted to the new conditions (that adapted to the colder climates of the earth moving more towards the equator), its remains, at least such as were preserved, spreading over those of the animals and plants which flourished in the same regions under higher temperatures.

The like general effects would be expected if, without supposing a diminished influence of the sun, our whole solar system, moving through space, should pass from the temperature now inferred to be that of the portion amid which that system takes its course (p. 206) to one less high. And it may well deserve the attention of the geologist to consider the effects which would follow such a change, even to the amount of a few degrees, as commonly measured by thermometers. In his observations on the distribution of masses of rock, apparently ice-borne to their present positions, and about to be noticed, it is very desirable that he should regard the subject generally as well as locally, so that, whatever may eventually appear the right inference to be drawn from the facts recorded, such as may bear upon the former should not be omitted in the search for the latter. As regards the evidence of many climates having remained much the same, with certain modifications, during those comparatively few revolutions of our planet round the sun, of which we have any records, and from which we may infer that the climates generally of the surface of the globe have not suffered material alteration since the historical period, as it has been termed, the geological observer will soon perceive that he is forced to consider it as affording him very limited aid in his inquiries respecting the former climatal conditions of the earth.

The present different conditions as to the production of ice capable of transporting mineral matter, in the manner above noticed, in the northern and southern cold regions of the globe, are sufficient to prove that partial changes of great importance may arise from differences on the surface of the earth itself. Every-day experience in geological research will show the observer that he has to consider the surface of the earth to have been in an unquiet state from remote geological times to the present, and that while

he so often stands, amid stratified deposits, on ancient sea-bottoms now elevated to various altitudes above the ocean level, many a region shows that its area has more than once been beneath that level and above it. Thus, although a mass of land may now rise above the sea-level at the South Pole, separated by a broad band of ocean from other great masses of land to the northward, producing certain effects as regards the climate of that part of the globe, and the northern polar regions are otherwise circumstanced, it by no means follows that such has always been the case, even in more recent geological times. If we change the conditions of the two polar regions, a difference of results is obtained of an important geological character. Mr. Darwin has skilfully touched upon the effects which would follow such a modification of conditions, and which require to be borne in mind in researches of this kind.*

In like manner any elevation or depression of a considerable area of dry land, which should raise parts of it above, or lower others, now above, beneath the line of perpetual snow, would produce modifications in the transport of mineral matter which could be effected

* He transports, in imagination, parts of the southern region to a corresponding latitude in the north. "On this supposition," he observes, " in the southern provinces of France, magnificent forests, intwined by arborescent grasses, and the trees loaded with parasitical plants, would cover the face of the country. In the latitude of Mont Blanc, but on an island as far eastward as Central Siberia, tree-ferns and parasitical orchideæ, would thrive amidst the thick woods. Even as far north as Central Denmark, humming birds might be seen fluttering about delicate flowers, and parrots feeding amidst the evergreen woods, with which the mountains would be clothed down to the water's edge. Nevertheless, the southern part of Scotland (only removed twice as far to the eastward) would present an island "almost wholly covered with everlasting snow, and having each bay terminated by ice-cliffs, from which great masses, yearly detached, would sometimes bear with them fragments of rock. This island would only boast of one land-bird, a little grass and moss; yet, in the same latitude, the sea might swarm with living creatures. A chain of mountains, which we will call the Cordillera, running north and south, through the Alps (but having an altitude much inferior to the latter), would connect them with the central part of Denmark. Along this whole line nearly every deep sound would end in 'bold and astonishing glaciers.' In the Alps themselves (with their altitude reduced by about half), we should find proofs of recent elevations, and occasionally terrible earthquakes would cause such masses of ice to be precipitated into the sea, that waves, tearing all before them, would heap together enormous fragments, and pile them up in the corner of the valleys. At other times, icebergs, charged with no inconsiderable blocks of granite, would be floated from the flanks of Mont Blanc, and then stranded in the outlying islands of the Jura. Who, then, will deny the possibility of these things having taken place in Europe during a former period, and under circumstances known to be different from the present, when, on merely looking to the other hemisphere, we see they are under the daily order of events?" Mr. Darwin then calls attention to the island groups, "situated in the latitude of the south part of Norway, and others in that of Ferroe. These, in the middle of summer, would be buried under snow, and surrounded by walls of ice, so that scarcely a living thing of any kind would be supported on the land."—Narrative of the Surveying Voyages of the Adventure and Beagle, vol. iii. p. 291.

by ice. If the region comprising the Alps were raised 3,000 feet above its present relative level, the area fitted for the formation of glaciers would be greatly extended, many a valley would be filled with ice, and many a mountain would contribute its glacier, not so filled or contributing at the present moment. Blocks and minor fragments of rocks would be ice-borne over, and left at distances from the main range not now attained; and, under the supposition of a gradual rise of land, many modifications would attend the change in the perpetual snow line, whence the glaciers for the time took their rise. Many a ravine and mountain side would be grooved and scratched not now touched by glaciers, and huge masses of rock be accumulated in heaps or lines, in localities where no ice now transports such masses. Assuming a depression of the same area, if we take the present relative levels only into consideration, the transport of glacier-borne blocks and fragments of rock, with the polishing, grooving, and scratching of valleys and their sides by the moving ice, would be limited to the areas now occupied by glaciers, duly allowing for their extension and contraction within the range of the present climatal conditions.

Thus, by the elevation and depression of large areas of dry land, very varied conditions for the existence, extension, or contraction of glaciers, with their geological consequences, may arise, without reference to those due to floating ice, excepting such as could be formed in great lakes, such as that of Geneva, for example, where effects similar to those observed in northern America would be produced. On the shores of such lakes coast ice would be formed, enclosing fragments of the rocks, and the shingles of beaches, to be borne away, should circumstances permit, if raised to an altitude permitting a depression of temperature sufficient for the production of such ice. There is also no difficulty in imagining conditions under which glaciers could protrude into large fresh-water lakes, carrying rock fragments with them, and having their extremities broken off and floated away with their detrital loads, under proper depths of water, as now takes place in the sea in the polar regions. Such masses of ice, though not moved onwards by streams of tide or ocean currents, would still be under the influence of the winds, to be driven to, and stranded in minor depths, where the ice could melt, and leave any blocks or fragments entangled in or resting upon them.

With respect to the distribution of ice-borne blocks of rock upon lakes, Sir Roderick Murchison has called attention to effects which would follow the lowering of lakes in regions where ice could be

formed of sufficient thickness and importance for the transport of detritus.*

When the depression of an area of dry land, with the needful modifications of surface, in climates where glaciers had been formed, was such that the sea entered amid the valleys in which these streams of ice occurred, the change might or might not, according to the general climatal conditions produced, affect the glaciers. Should the change in the northern be of an order to introduce the climate of the southern hemisphere, it has been above seen (p. 240), the cold might be so increased, that Alpine glaciers became more extended, delivering icebergs into surrounding seas, so that, as Mr. Darwin has remarked (note, p. 253), they might float away, and be stranded on the Jura, then an island range.

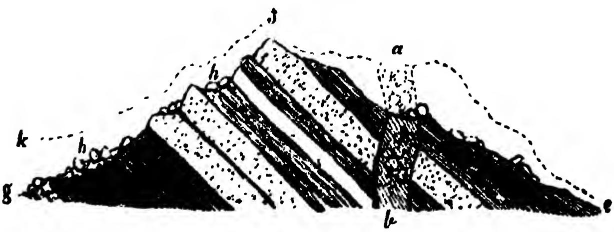
Hitherto we have regarded these alterations of level as slowly produced, so that the changes, of whatever kind, were gradual, causing no sudden alteration of conditions. This, however, is far from necessary in geological reasoning, there being evidence connected not only with actual mountain ranges, but also with many a district wherein the rocks are broken and contorted, which would lead us to infer, with every allowance for the repeated effects resulting from the multiplied application of minor forces, that considerable forces had often been somewhat suddenly called into action. The waves produced during the disturbances of the land, known to us as earthquakes, and which will be noticed hereafter, are sufficient to show how, in that mode alone, glaciers, protruding into the sea, or great lakes of fresh water, may be lifted at their ends, and their fragments, with any load of detritus they may sustain, be whirled about and stranded in unusual situations. Greater waves would produce greater results, and when we unite them with land suddenly depressed beneath the sea-level, even only a few hundred feet, in such regions as those of Victoria Land and South Georgia, or of Greenland and Iceland, we have the means of removing ice and producing a complicated mixture of blocks and minor fragments of rock of great geological importance. In like manner, the sudden elevation of land, covered by snow and glaciers, if accompanied by the transmission of heat through fissures then formed, or by the increased temperature of the supporting mineral matter from the protrusion of igneous rocks among it, so that the snow and ice were suddenly and in part melted, would be productive of no slight geological effect, more especially if the glaciers of the land so acted upon protruded, or nearly so, into the sea.

* "Geology of Russia in Europe and the Ural Mountains," vol. i. p. 568.

Huge blocks of rock, often angular, are found scattered in such a manner over parts of the northern portions of Europe and America, and again in part of South America, and amid and around mountainous regions, such as the Alps, that, comparing their mode of distribution with that now known to be taking place by means of ice, attention has of late been very generally given to this explanation of their mode of occurrence. The masses of rock so found are commonly termed *Erratic Blocks*, and correct observations respecting the conditions under which they are found are material to a right understanding, particularly as respects the northern hemisphere, of the manner in which they have been accumulated.

As there are occasionally blocks of rocks scattered over a country, which are merely portions of some harder beds, interstratified with more yielding substances, or are the remains of dykes and veins of igneous rocks, the continuity and mode of occurrence of which may not be clear, the more readily disintegrated rocks having been removed by the effects of atmospheric influences, or breaker action at some prior geological time, the observer has in some districts to employ much caution as respects their origin. This is especially needed where the dykes or veins of the igneous rocks may have decomposed, as often happens, in an irregular manner, so that portions of the more unyielding, or harder parts, are scattered about, while traces of the softer are not easily found. From the liability of certain igneous rocks to decompose in spheroidal forms (fig. 2, p. 3, and fig. 7, p. 9), such blocks will sometimes present the false appearance of having been rounded by attrition, as if worn on some coast. Let, for illustration, *a*, *b*, be a dyke of greenstone, liable to

Fig. 96.

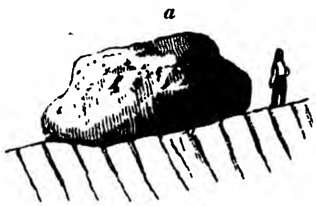


unequal decomposition in different parts, at *a* decomposed in spheroidal portions, then during the loss of general surface upon the hill side *e f*, the harder parts of the disintegrated portion, *a c*, might fall over towards *e*, and present the appearance of rounded boulders of greenstone resting upon some other rock. Again, on the other side of the hill, *f g*, there might also be angular fragments of rock,

h h, detached from the harder beds above them, during a loss of matter from an old surface, *f k*. This kind of precaution has frequently to be taken in granitic regions, the blocks of granite often decomposing in a rounded form, so as, when scattered about amid bogs, and much disintegrated rock, to present the appearance of boulders rounded by attrition.

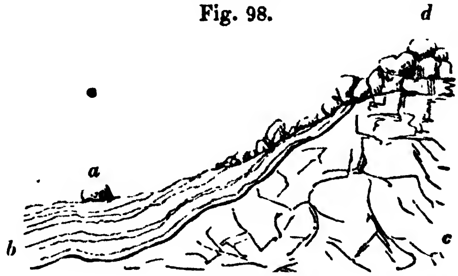
The tendency to decompose in spheroidal forms has also to be sometimes well considered when it is inferred that such rocks, even when they are true erratic blocks, have been rounded by attrition before they were ice-transported. A block of granite, for example, such as that represented beneath, *a* (fig. 97), though now rounded,

Fig. 97.



may have been transported in a more angular condition, the removal of the angular parts having been effected by decomposition, from atmospheric influences, since it occupied its present position. In this manner, rounded blocks of granite may be scattered down a mountain side, as in the following section (fig. 98), where granite,

Fig. 98.



c, rising in a tor, *d*, above certain stratified deposits, *b*, has fallen in blocks, down the slope, a large rounded block presenting itself at *a*. Although it may have so happened that such a state of things had been brought about by the motion of a glacier, leaving lateral moraines (other fitting conditions obtaining), or by coast ice carrying blocks of rock, it still becomes needful to ascertain that such are not blocks fallen from the heights, and simply rounded by decomposition, which a careful examination of the granite at *d*, would aid in showing.

As under the hypothesis of cold having once prevailed in the northern hemisphere, greater than at present, much of the land then submerged is now raised above the level of the sea, and consequently an upward movement of a large portion of northern Europe, Asia, and America inferred, it becomes of no slight interest to see how far ice, in its various modes of occurrence, could be the means of producing the distribution of the rock fragments, often of great magnitude, there found. Assuming the submergence, it becomes desirable to see if its amount can be ascertained. There is always the difficulty of knowing how much portions of rock, of various sizes, may have been rounded and left on coasts and in river courses over the older accumulations, anterior to this supposed ice or glacial period in the northern hemisphere. Giving this, however, its full value, we should expect, as the land rose and the temperature became gradually elevated to that which we now find, that, under certain favourable circumstances, glaciers which were previously cut off by the sea, floating away their terminal portions, might for a time become more extended over dry land, thrusting forward their moraines further than formerly. Thus the levels at which the remains of true terminal moraines could be found, might not give the amount of submergence sought, even supposing that they could be fairly separated from other accumulations of rocks which they may more or less resemble. Coast accumulations of the time, if they could be traced, would be more certain guides.

Still assuming a gradual disappearance of ice, up to the amount now found in the northern regions, and consequently the entire disappearance of many glaciers on lands, such, for example, as the British Islands, where they are supposed to have occurred at the glacial period, the various moraines, as also the polished surfaces, grooves, and scratches formed by the glaciers, would be gradually left to be dealt with by atmospheric influences, and the modifications and changes brought about by them, vegetation spreading over the land as the snow and ice disappeared.

The land rising, and the deeper parts becoming more shallow, mud, previously beyond the action of the wind-waves moving on the surface, would be caught up in mechanical suspension, to be carried to more quiet situations by streams of tide (in tidal seas), or sea-currents, where these began to act. The same with the other portions of the sea-bottom: fragments of rock, of various forms and sizes, thrown down from portions of glaciers, river ice, and coast ice, as they floated above and gradually parted with them, rising with the rest. While much fine sediment would be separated

from the larger detritus, as the wind-wave action became more and more felt, so that much of this sediment might be removed from amid the larger detritus, bringing the portions of the latter gradually into closer contact, it would be when the sea-bottom came within the action of the breakers, that the chief modifications of such previous sea-bottom would be effected. The new coasts would be adjusted to the conditions arising from their exposure to the force of the breakers, and the rise and fall of tides, where these were felt, and the angular fragments which had reposed quietly at the bottom, in the manner above noticed (p. 230), would be brought within the action of the breakers, to be rounded by attrition, large blocks standing out as many rocks now do on the sea-coasts. While previously ice-borne and rounded blocks and shingles would again be more worn, the angular fragments would be more or less rounded by the same action, according to their exposure to the breakers. Lines of beach would be thrown up in the usual manner, sandy or shingly, according to circumstances, and be left and be modified by atmospheric influences as the land rose, and the drainage of the old sea-bottom became adjusted to its various levels and inequalities of surface.

Under such circumstances, very variable results would be produced as conditions changed, and the component portions of the old sea-bottom were partly removed and partly left; dispersed ice-borne fragments of rock, rounded or angular as the case may have been, brought together, the angles of the latter sometimes completely rounded by breaker action, at others not much injured; the shells of molluscs and the harder parts of other marine animals sometimes removed and redeposited in a nearly uninjured state, at others, broken into fragments, and variously arranged amid the new accumulations of mud, sand, shingles, and boulders. Should there have been a tendency, under the old conditions of the sea-bottom, to have glacier ice, loaded with rock fragments, or coast ice, bearing away shingles, boulders, and also angular blocks floated away in particular directions, dropping their mineral burdens in lines, upon that bottom, such lines, as it rose, would be preserved according to circumstances. However separated large blocks might be by any other deposits effected during their gradual accumulation, there would be a tendency to remove the finer sediment from among them, so that they would finally present the aspect of lines, often, when the blocks were very thickly thrown down from the ice, forming ridges. Such ridges would, however, be acted upon by breakers

rise of the land, so that detritus might be strewed upon them in the manner of beaches, and thus a complicated arrangement of parts be produced.

During such changes, icebergs derived from glaciers would float about until the parent glaciers either disappeared or became separated from the sea, and the coast ice formed would become gradually limited in its production up to its present adjustment. Various new modifications would arise from the formation of coast ice, as also from the river ice, as the drainage of the old land found its way amid the new land, with the rain and spring waters of the latter, to the sea. Many blocks of rock would be caught up on the coast, and be transported elsewhere, as was the case with the block on the coast of Denmark, mentioned by Professor Forchhammer (p. 247), and rivers flowing in certain directions might carry back blocks of rock towards their parent masses, as noticed by Sir Roderick Murchison* in the manner that blocks are now moved northwards by the Volkof and Msta.

Under the hypothesis, therefore, of lower temperature accompanied by more sea, the bottom of much of which has since become dry land in the northern hemisphere, the observer has not only to study a wide range of country for evidence of the land supposed to be originally above the water, variously snow-clad, and furnishing glaciers, the terminal parts of which, from time to time, floated away, with the coast ice and extension probably of ice barriers, but also the modifications which the old sea-bottom has undergone in its rise above the sea. Thus he would often have to separate, and duly weigh, much evidence which might, at first, appear somewhat contradictory as to erratic blocks having been transported by land ice or sea ice—as to the polishing, grooving, and scratching of subjacent rocks by the one or the other, and as to the original arrangement and rearrangement of many detrital accumulations.

It may be instructive to consider the effects which would follow the submergence of the British Islands, and of an adjoining portion of France, to 1,000 feet beneath the level of the seas which now surround and adjoin them. And it should be noticed that of a submergence to this, and even a larger amount at a comparatively recent geological period, there would appear good evidence. A glance at the accompanying map (fig. 99), which represents the

* "Geology of Russia in Europe and the Ural Mountains," vol. i., p. 565.

land that would, under this hypothesis, be above water, will show numerous islands and islets variously distributed.* The largest amount of dry land would be found in Northern Scotland, and be divided into two main portions by a strait, now occupied by the low ground and lakes between the Murray Firth and Loch Linnhe. Off these principal islands there would be many minor islets, chiefly on the south and south-west. In Southern Scotland there would also be a patch of dry land, of some size, and in Cumberland and Westmoreland another; while a somewhat comparatively large island would extend, in a north and south direction from Westmoreland, by Yorkshire into Derbyshire. In Wales there would be much land above the level of the sea, with many detached islets there and in some parts of England; among them the tops of the Malvern hills, which now at a distance present so much the appearance of an island.† In Ireland there would be numerous islets, the chief island being formed by the Wicklow mountains and their continuation. From them, to the westward, many islets would rise above the sea. As a whole, the Irish islets would be principally gathered into two groups, one on the north, the other on the south.

Taking this submergence, with a climate resembling that of Tierra del Fuego and South Georgia, so that such islands as were sufficiently high were snow-clad, glaciers would descend into the valleys, even occasionally reaching the sea, their terminal portions loaded with blocks and fragments, these floated off by the ice, and strewed over the bottoms of the neighbouring seas according to circumstances. And respecting the heights of the islands, many would rise to sufficient altitudes for these effects to be produced, Lugnaquilla being still 2,039 feet above the sea, Ben Nevis 3,373 feet, Skiddaw 2,022 feet, and Snowdon 2,571 feet. If to this we add the coast ice, with its effects as above noticed (p. 245), there would be no want of conditions for the distribution, by means of ice, of blocks of rock of various sizes and kinds, and of fragments

* The light portions of the map represent the parts of the present land, which would appear above water if it were submerged 1,000 feet; the next shade will be readily recognized as the present outlines of the British Islands; the darker shade corresponds with the depth of 600 feet (100 fathoms) around these islands, and the black portion with the deeper oceanic waters.

† A study of the Malvern district is not only interesting as showing how long the Malvern hills retained their insular character during the emergence of the British Islands to their present relative level, but also as regards the island state of the same hills at a far more remote geological period, one anterior to the accumulation of the rocks commonly known to British geologists as the New Red Sandstone. A detailed account of this district is given by Professor John Phillips, "Memoirs of the Geological Survey of Great Britain," vol. ii., part 1.

of all forms over the area now presented by the British Islands, at various levels beneath that corresponding with an altitude of 1,000 feet above the present sea level. While this was being accomplished, the formation of moraines, and the polishing, grooving, and scratching of rocks, through the instrumentality of glaciers, would be effected above that level, up to altitudes where glacier action of that kind could be then felt. At the sea level, and at such depths beneath it as its influence could be felt, coast ice would be the means of polishing, grooving, and scratching rocks exposed to its action; icebergs would ground, producing their effects, and such rivers as moved rocks by means of ice would add their ice-transported detritus.

A submersion of the British Islands to 1,000 feet beneath the present level—a change in the relative level of sea and land which, however startling it may be to those unaccustomed to geological investigations, the observer will soon learn to consider as one of a minor kind,—could scarcely fail to be accompanied with a submersion of various adjoining portions of Europe. It is not needful to infer that the relative change of level was of equal amount through a very considerable area. It may have been greater in some regions, less in others; but let this have been as it may, such a change would probably bring about a very material difference in the distribution of land and sea, as we now find it. Among other modifications, the Scandinavian regions might be brought under conditions by which, should currents permit, blocks and fragments of rocks, and of various sizes and forms, could be borne by icebergs or coast ice, and be distributed over the bottoms of the seas then on the southward of them, some even being drifted to the area of the British Islands, mingling here and there with their own ice-distributed detritus.

In such changes, not only has the geologist to bear in mind the different distribution of sea and land, but also the modification of tidal action and sea currents effected, duly giving attention to the probable extension of coast-ice, even, perhaps, sometimes amounting to great icy barriers. Though some value would have to be attached to the influence of the outstanding group of islands and islets then rising above the area now more extensively occupied by the British Islands, the waves of the Atlantic would roll over a large tract now forming a portion of Northern France, with Belgium, Holland, Denmark, Northern Germany, and an extended area in Russia. The conditions producing the action of the tides surrounding the British Islands being changed, others would arise

suited to the new arrangement of land and sea, and many a mass of ice in the Scandinavian regions, so long as it rested on sea-bottoms, would act as land in the modification of tidal streams and sea currents.

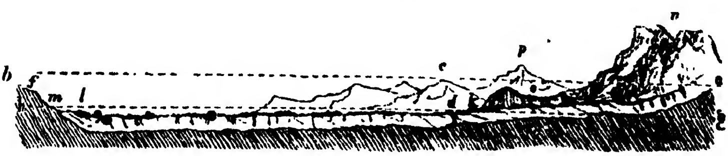
How far the outlines of the land may have generally resembled the present at the commencement of these changes it would be difficult to say, since many modifications have been produced while such changes were effected, and the submergence may have commenced when more land was above the sea level than at present, somewhat more corresponding with the line of 600 feet now beneath the sea, around the British Islands, as in the plans, fig. 65 (p. 91), and fig. 99 (p. 261). Taking, however, the present distribution of sea and land as a guide, and looking chiefly to the production of ice (other consequences of submerging and emerging land being reserved, in a great measure, for subsequent notice), we have to consider an increase of cold on the one side, and a decrease of dry land accompanied by a loss of height, on the part still above water, on the other. For convenience we may regard these changes as gradual, the modifications arising from more rapid change being readily appreciated.

The gradual increase of cold would tend to lower the line of perpetual snow over the dry land, while the rate of its descent down any mountain range would depend upon the rate of submergence of the land. They might balance each other. Should the rate of decrease of temperature be more rapid than would be compensated by the submergence, pre-existing glaciers would increase even during the descent of the land, and new glaciers would establish themselves elsewhere under the needful conditions. Assuming, however, the continued increase of cold, a time would come, even if the pre-existing glaciers did not much increase during the submergence of the land, when those formed in Scandinavia could reach the sea, as now in Greenland, distributing detritus by their detached portions bearing rock fragments to the adjacent seas.

Looking to other portions of Europe with reference to this submersion of 1,000 feet, or thereabouts, it may not be uninstructive to consider the effects of the cold inferred upon the glaciers of such regions as the Alps, and the establishment of new glaciers in other mountainous districts where the needful conditions may have been produced. In the Alps the glaciers would increase, as they now do, under the influence of certain seasons; but instead of that decrease which brings them back to a certain state from a modification of the seasons in another direction, the increase would continue,

an extension of the sea from the Atlantic being not unfavourable for this purpose, independently of the greater cold produced. Under such circumstances, glacier-borne blocks and other rock fragments, which would have been left in many a locality, or carried forward to the terminal moraines, would continue to advance with the augmented length and volume of the glaciers, until they were finally arrested in their progress by the conditions affecting the extent of the glaciers themselves. If the observer will study the occurrence of existing glaciers upon maps or models of the Alps and adjoining districts,* he will perceive that the outward courses of existing glaciers would be greatly extended, while many a new glacier would contribute its ice to the general mass, sometimes carrying its own moraines, and at others modifying the courses of the main streams of ice into which it might merge. With a change of temperature and of relative level of sea and land, which should bring down the altitude of the present line of perpetual snow in the Alps to that of Chiloe (between 40° to 43° S., the Alps being between 42° and 47° N.), it would descend about 2,500 feet, and with it the névé of the glaciers. This descent of the snow-line being supposed gradual, the glaciers would advance as gradually, and the blocks derived from the present interior portions of the Alps would be moved onwards in front. Let, in the following section (fig. 100),

Fig. 100.



a, b, be the level of perpetual snow in a range of mountains amid which glaciers are formed, *d,* the extension of one of these glaciers under any given, yet needful, conditions; *c* and *f,* mountains, just beneath the line of perpetual snow. If now the conditions so change that *g h* becomes the perpetual snow line, those for the production of glaciers continuing, the supply of the original glacier will take place at a lower level, while the ice which only extended to *d,* would be forced onward, on the same principle as the ordinary, however temporary, increase of a glacier may be affected.

* The map accompanying "Travels in the Alps of Savoy," &c., by Professor James Forbes, upon which the glaciers of the districts visited are very carefully entered, will be found very useful for this purpose, and more especially with reference to the inferred extension of glaciers down the valley of the Rhone to the Jura.

With it any collection of blocks, thrust forward in the usual manner to *k*, would be moved onward, with the ice, to *l*, and possibly to *m*, the proper conditions prevailing.* With such increase a collateral glacier might come in from a valley *o*, between *n* and *c*,

* Regarding the extension of Alpine glaciers from increased cold, continued through a certain amount of geological time, the slopes over which they may be inferred to have passed require attention, due allowance being made for the effects which would arise from the supposed greatly-increased volume of many glaciers. As connected with this subject, M. Élie de Beaumont has given ("Note sur les pentes de la limite supérieure de la zone erratique," &c., Annales des Sciences Géologiques, 1842) the following table for the upper limit of the erratic block zone of the valley of the Rhone, &c.:—

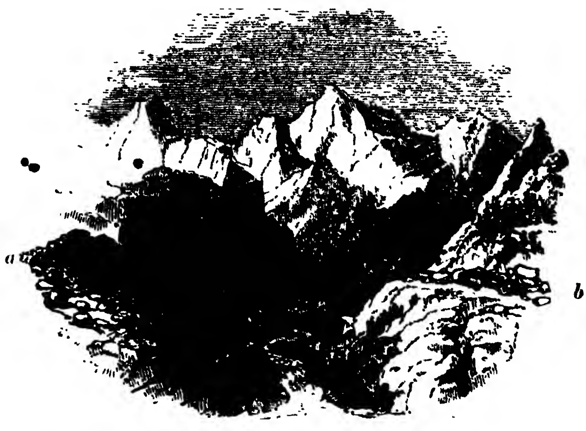
Localities.	Distances.	Differences in the Height of the two Localities.	Inclination.		
	Metres.	Metres.	°	′	″
Grimsel. Aernen.	25,000	487	1	6	57
Aernen. Brieg.	10,000	293	1	2	56
Brieg Martigny	80,000	70	0	3	1
Great St. Bernard Plan-y-beuf	15,000	731	2	47	24
Plan-y-beuf Martigny	18,000	319	1	0	55
Martigny Monthey	18,000	293	0	55	57
Montigny Mimisse	44,000	425	0	33	12
Mimisse Geneva.	49,000	585	0	41	2
Martigny Playau.	44,000	228	0	17	48
Martigny Chasseron	92,000	400	0	14	55
Playau Chasseron	49,000	172	0	12	4
Plan-y-beuf Chasseron	110,000	719	0	22	28
Great St. Bernard Chasseron	125,000	1,450	0	39	52
Grimsel. Martigny	121,000	850	0	24	9
Grimsel. Playau.	165,000	1,078	0	22	27
Grimsel. Chasseron.	213,000	1,250	0	20	10
Aernen. Playau.	140,000	591	0	14	3
Névé of the Ober Aer Grimsel. Level of the Roches Moutonnées	13,500	624	2	38	45
Grimsel. Brunig.	29,000	1,037	2	2	52

M. Élie de Beaumont remarks that he does not know in the Alps any glacier which moves through any considerable extent, such as a league, with a slope much less than 3°.

perhaps the extension of a small glacier previously formed at *p*, or altogether new; and thus blocks and glaciers may descend against the extension of the main glacier to *m*. The face of the Alps, as regards snow and ice, would be most materially changed by a descent of the snow-line, so as to be of about the same altitude as that of Chiloe, and a further decrease of temperature would necessarily still further extend the glaciers.

Assuming a depression of this kind, the observer has to take into consideration the rise of the sea-bottom to the present European levels of sea and land, accompanied by an elevation of general temperature to that now found. As the land rose, beaches would be left in various situations, showing the different alterations of the relative levels of sea and land. Should considerable pauses in the elevation of the land have taken place, these would be marked by lines of cliff, where the rocks could be sufficiently worn by the breakers. The production of coast ice would gradually become less, so that its formation would cease in the southern lands, and the glaciers generally would decrease, leaving their lines of moraines, and many angular blocks of rock, perched on the sides of mountains, as in the following sketch (*a*, *b*, fig. 101), at altitudes corresponding

Fig. 101.



with the volumes of their transporting glaciers at the periods of their chief extension down valleys, where only a remnant of such glaciers may be now left at their higher extremities, or even, as in the British Islands, no portion of one may remain.

The land continuing to rise, not only would the previous sea-bottom, with its varied accumulations (in some of which the remains of animal life would be entombed, often in regular beds of sand, silt,

and mud), be brought within the destructive influence of the breakers, as above noticed (p. 258), but rivers also would begin to flow amid the old sea-bottom. According to circumstances, such rivers would present varied characters, and some would carry forward ice-borne detritus to the sea, or leave it on their courses, as it might happen, until only certain of them, those now possessing the needful conditions, so transported mineral substances.

From the interest which has been excited respecting the transport of erratic blocks, many of great volume, by means of ice, a mass of information has been collected, rendering the submersion of a large portion of Northern Europe, Asia, and America, accompanied by a considerable depression of temperature, extremely probable. The effects of floating ice have for a long time engaged attention. Professor Wrede, of Berlin, would appear to have been among the first to account for the erratic blocks on the south of the Baltic, by means of floating ice, there having subsequently been a change of level in that region, by which the sea-bottom became dry land.* Sir James Hall also long since referred to floating ice, combined with earthquake waves, as a means of transporting erratic blocks; † and its aid, under various conditions, has been sought in explanation of the transport of large and often angular blocks of rock from their parent masses to considerable distances. Though Professor Playfair long since (1802) pointed out glaciers as having been the means of carrying erratic blocks,‡ even (in 1806) inferring that those on the Jura may have been transported by the extension of ancient Alpine glaciers to that range of mountains, the subject engaged no great attention for some time. M. Venetz appears to have been the first who, having had occasion to study glacier

* "Geognostical Researches relative to the Countries on the Baltic, and particularly to the Low Lands at the Mouth of the Oder, with Observations on the gradual change of the Level of the Sea in the Northern Hemisphere, and its physical causes, as quoted by De Luc, Geological Travels, 1810." Professor Wrede supposed a slow change in the centre of gravity of the earth, so that the waters retreated from the northern hemisphere, leaving the sea-bottom dry, with the ice-borne blocks of rock upon it. He calculated the ice needed to float an erratic block, estimated to weigh 490,000 lbs., occurring at the mouth of the Oder.

† "On the Revolutions of the Earth's surface" (1812), Transactions of the Royal Society of Edinburgh, vol. vii., p. 157. After noticing the removal of a block of rock four or five feet diameter, being a boundary mark between two estates on the shore of thé Murray Frith, by the tide, while encased in ice, for 90 yards, and also the magnitude and effects of earthquakes, he asks, respecting the erratic blocks of Northern Europe, if both combined would not produce the effects required, "the natural place of these blocks being covered perfectly with ice, in the state best calculated for fulfilling the office here assigned it," p. 157. He inferred that in the Alps similar waves, assuming the fitting conditions, would wash off portions of glaciers with their load of blocks.

‡ Playfair, "Illustrations of the Huttonian Theory," § 349.

movements, subsequently (1821) took the same view;* one adopted afterwards (1835) by M. de Charpentier,† and further extended (in 1837) by M. Agassiz.‡ The subject then attracted more general interest, especially from the writings of M. de Charpentier § and M. Agassiz,‖ and the consideration of the effects produced by existing glaciers and floating ice, with the probability of a colder state than at present of the northern portions of Europe, Asia, and America, at a comparatively recent time, now form one of the usual objects of geological investigation.

Sir Charles Lyell long since called attention to the distribution of blocks and minor fragments of rock over the sea-bottom by means of icebergs, and to the manner in which such detritus would be found scattered over various levels, if this sea-bottom were upraised and formed dry land.¶ Subsequently (in 1840) after noticing the action of drift ice, charged with mud, and blocks of rocks, he pointed out the manner in which floating ice may, by grounding upon coasts or banks, so squeeze the upper layers of mud, sand, and gravel, that contorted masses of these layers may repose upon undisturbed and horizontal beds beneath.** It was, however, in consequence of a visit to this country by M. Agassiz, in 1840, and upon the extension of his views respecting glaciers to the British Islands,†† that the former existence of glaciers in them has attracted

* Venetz, "Bibliothèque Universelle de Genève," tom. xxi., p. 77, and "Denkschriften der Schweizerischen Gesellschaft;" 1 Band, Zurich, 1833.

† De Charpentier, "Notice sur le cause probable du Transport des Blocs Erratiques de la Suisse, "Annales des Mines," 3me Series, tom. viii., 1835.

‡ Agassiz, "Address before the Helvetic Society of Natural Sciences, at Neufchatel," 1837.

§ "Essai sur les Glaciers et sur le Terrain Erratique du Bassin du Rhone," Lausanne, 1841.

‖ "Etudes sur les Glaciers," 1840.

¶ "Principles of Geology," 1832.

** In a communication on the Boulder Formation or Drift, and associated fresh-water deposits, composing the mud cliffs of Eastern Norfolk, "Proceedings of the Geological Society of London" (January, 1840), vol. iii., wherein the contortions observed on that coast are thus explained.

†† In the "Proceedings of the Geological Society of London," vol. iii., p. 328 (1840), M. Agassiz has given a summary respecting his views of the former existence of glaciers in the British Islands. Ben Nevis, in the north of Scotland, and the Grampians in Southern Scotland, are considered by him as the great centres of dispersion of erratic blocks by glacier ice in that part of Great Britain. He pointed out the mountains of Northumberland, Westmoreland, Cumberland, and Wales, as well as those of Ayrshire, Antrim, Wicklow, and the West of Ireland, as also centres of dispersion, "each district having its peculiar débris, traceable in many instances to the parent rock, at the head of the valleys. Hence," observes M. Agassiz, "it is plain the cause of the transport must be sought for in the centre of the mountain ranges, and not from a point without the district." The Swedish blocks on the coast of England do not, he conceives, contradict this position, as he adopts the opinion that they may have been transported by floating ice," p. 329. He considered that the best example of glacier striated rocks in Scotland is to be seen at Ballahulish.

attention. Numerous facts have since been adduced in support of this opinion by Dr. Buckland, Sir Charles Lyell, Professor James Forbes, Mr. Darwin, and others.* The amount of submergence at

* Dr. Buckland ("Proceedings of the Geological Society of London," vol., iii. p. 332, 1840), in his paper, "On the Evidences of Glaciers in Scotland and the North of England," points out localities which he infers show the remains of moraines near Dumfries, in Aberdeenshire, in Forfarshire, at Taymouth, Glen Cofield, and near Callender, with evidences of ancient glaciers on Schiehallion, in and near Strath Earn, and near Comrie; and of glacial action at Stirling and Edinburgh. He also mentions moraines in Northumberland, the evidence of ancient glaciers in Cumberland and Westmoreland, and the dispersion of Shap Fell granite by ice.

In his address to the Geological Society of London, as its President, in February, 1841, Dr. Buckland gave a condensed statement of the progress of investigations on this subject during the preceding year, one in which the "Glacial Theory," was so much considered.

Dr. Buckland subsequently, in his memoir on the Glacia-Diluvial Phœnomena in Snowdonia, and the adjacent parts of North Wales (December, 1841), "Proceedings of the Geological Society," vol. iii., p. 579, described the rounded and polished surfaces, often accompanied by grooves and scratches, attributed to glacier action, in the valleys of Conway, of the Llugwy, of the Ogwyn, of the Sciant, and of Llanberis, of Gwyrfain or Forrhyd, of the Nautel or Lyfni, and of the Gwynant.

Sir Charles Lyell, in his paper "On the Geological Evidence of the former existence of Glaciers in Forfarshire," stated that though, for several years he had attributed the transport of erratic blocks, and the curvature and contortions of the incoherent strata of gravel and clay, resting upon the unstratified till, to drifting ice, he had found difficulty in thus accounting for certain other facts connected with the subject, until Professor Agassiz extended his glacial theory to Scotland. After a description of various minor districts, Sir Charles Lyell observes, "that it is in South Georgia, Kerguelen's Land, and Sandwich Land, we must look for the nearest approach to the state of things which must have existed in Scotland during the glacial epoch."

Professor James Forbes, in his "Notes on the Topography and Geology of the Cuchullen Hills, in Skye, and the traces of ancient glaciers which they present," (Edinburgh New Philosophical Journal, 1846, vol. xl., p. 76), points out groovings and scratchings upon polished rocks of a marked kind. He observes, respecting the valley of Coruisk, that "the surfaces of hypersthene, thur planed or s--ened, present systems of grooves exactly similar to those so much insisted on in the action of glaciers on subjacent rocks, and as evidence of glaciers in parts of the Alps and Jura, where they are now awanting. These grooves or striæ are as well marked, as continuous, and as strictly parallel to what I have elsewhere shown to be the necessary course of a tenacious mass of ice urged by gravity down a valley, as anywhere in the Alps. They occur in high vertical cliffs, as near the Pissevache; they *rise* against opposing promontories, as in the valley of Hasli; they make deep channels or flutings in the trough of the valley, as at Pont Pelissier, near Chamouni; and as at Fee, in the Valley of Saas. At the same time these appearances have a *superior limit*, above which the craggy angular forms are almost exclusively seen, where the phenomena of wearing and grooving entirely disappear. In short," adds Professor Forbes, "it would be quite impossible to find in the Alps, or elsewhere, these phenomena (except only the high polish which the rocks here do not admit of) in greater perfection than in the Valley of Coruisk." Other evidence of the like kind is also adduced.

Mr. Darwin, in his "Notes on the effects produced by the ancient Glaciers of Caernarvonshire, and on the boulders transported by floating Ice" (Philosophical Magazine, 1842, vol. xxi., p. 180), after mentioning the labours of Dr. Buckland, on the same country, and that Mr. Trimmer had first noticed ("Proceedings of the Geological Society," vol. i., p. 332, 1831) the scoring and scratching of rocks in North Wales, adduces additional evidence of glacial action in that district. He observes

this period has been variously estimated. Mr. Darwin infers, from a large greenstone boulder on Ashley Heath, Staffordshire, at 803 feet above the sea, and apparently derived from Wales, a considerable depression of England beneath the sea, and that Scotland, from other data, must have been submerged 1,300 feet.* Looking at the heights to which gravels extend in Wales, often apparently the remains of masses of coast shingles and sand, a like, if not a greater depression beneath the present sea level would be there required. In Ireland, we find large blocks of granite sometimes perched on the heights, amid grooves and furrows on the surface of the rocks beneath, at altitudes of 1,000 feet and more. In some cases we almost seem to have before us a portion of the very blocks which scratched and scored the subjacent rock-surfaces.†

Erratic blocks, occasionally of considerable magnitude, are found, in some localities, at various elevations above rocks of their kind, and from which they are considered to have been detached. Although it is obvious that each fragment, so detached, has deprived the mass of rock whence it has been derived, of so much of its volume, and perhaps also of its height, as regards elevation above

---

that, "within the central valleys of Snowdonia, the boulders appear to belong entirely to the rocks of the country. May we not conjecture," he continues, "that the icebergs, grating over the surface, and being lifted up and down with the tides, shattered and pounded the soft slate rocks, in the same manner as they seem to have contorted the sedimentary beds of the east coast of England (as shown by Mr. Lyell) and of Tierra del Fuego?" * * * The drifting to and fro and grinding of numerous icebergs during long periods near successive uprising coast lines, the bottom being often stirred up, and fragments of rocks dropped on it, will account for the sloping panes of unstratified till, occasionally associated with beds of sand and gravel, which fringes to the west and north the great Caernarvonshire mountains." Mr. Darwin further remarks (p. 186), as not "probable, from the low level of the chalk formation in Great Britain, that rounded chalk flints could often have fallen on the surface of glaciers, even in the coldest times, I infer, therefore," he continues, "that such pebbles were probably enclosed by the freezing of the water on the ancient sea-coasts. We have, however, the clearest proofs of the existence of glaciers in this country, and it appears that, when the land stood at a lower level, some of the glaciers, as in Nant Francon, reached the sea, where icebergs charged with fragments would occasionally be found. By this means we may suppose the great angular blocks of Welsh rocks, scattered over the central counties of England, were transported." The deposits of this date in Ireland have occupied the attention of several geologists, among whom may be mentioned, Mr. Weaver, Mr. Griffith, Colonel Portlock, Mr. Trimmer, Professor Oldham, Mr. Bryce, Dr. Lloyd, Mr. Hamilton, and Dr. Scouler.

* Philosophical Magazine, 1842, vol. xxi., p. 186.

† Although in several parts of Ireland the facts relating to the transport of erratic blocks can be well studied, and the altitudes at which they and the smoothing and scratching of surface rocks are found well observed, there are few places where the latter can be seen in greater perfection than the beautiful neighbourhood of Glengariff, county Cork. The scoring and rounding of the sides and bottom of the valley from the lower part of the demesne of Glengariff to Bantry Bay, and thence to the southward, in the direction of Cape Clear, are particularly worthy of attentive study.

the sea level, and consequently that if multitudes have been thus detached, previous heights, composed of such rocks, may have been much reduced by the loss thus sustained, there are instances where it would not appear a sufficient explanation to infer that a transport of erratic blocks had been effected by ice in such a manner, that, while higher portions of the parent rock floated away at the required levels, the remaining lower portions were denuded, in the usual manner, as the land emerged. To account for such instances, Mr. Darwin considers that we should regard the probable effects of submerging land, where coast ice could be formed, upon blocks of rock which may have been ice-transported to its shores. He points out that erratic blocks and other portions of the beaches of such shores might gradually be raised as the land became submerged, so that finally coast detritus, including the blocks of rocks ice-transported from various distances, would be elevated to heights above that at which it was accumulated or stranded. Blocks, with other coast fragments and shingle, would thus, when the land again emerged from beneath the sea, be found raised above the level at which the remains of their parent rocks are now found.*

Respecting the erratic blocks of the Alps, and of the adjoining countries, a large mass of information has been collected.† The main fact of the blocks and associated minor detritus having been transported from the higher Alpine mountains outwards on both sides the main ranges, showing that the cause of their dispersion had been in the Alps themselves, forms the base of the chief modern hypotheses connected with the subject, whether the sudden melting of snows and glaciers by the heat and vapours accompanying the last elevation experienced in these mountains,‡

---

* Darwin, "On the Transportal of Erratic Boulders from a Lower to a Higher Level."—Journal of the Geological Society, 1849, vol. v. Mr. Darwin remarks that the fragments of rock "from being repeatedly caught in the ice and stranded with violence, and from being every summer exposed to common littoral action, will generally be much worn; and from being driven over rocky shoals, probably often scored. From the ice not being thick, they will, if not drifted out to sea, be landed in shallow places, and from the packing of the ice, be sometimes driven high up the beach, or even left perched on ledges of rock."

† A valuable summary of the labours of geologists on this subject will be found in the "Histoire des Progrès de la Géologie, de 1834 à 1845," tom. ii., chap. 5, by the Vicomte d'Archiac. Appended to it is a list of the publications which may advantageously be consulted.

‡ As regards the transport of blocks of rock by the sudden melting of snow from the escape of gases rising through fissures during the elevation of mountain chains, the observer will find the subject carefully treated in the "Note relative a l'une des causes présumables des phénomènes erratiques,' by Élie de Beaumont (Bulletin de la Société Géologique de France, t. iv. p. 1334, 1847). On the supposed heat of the gases required for the melting of the snow, M. Élie de Beaumont remarks, after

the former great extension of Alpine glaciers, or the latter combined with a considerable submergence of land, so that the sea entered many of the valleys of the Alps, coast ice being possibly also produced.

Von Buch, De Luc, Escher, Élie de Beaumont, and other geologists, long since pointed out that, from the mode of occurrence of the Alpine erratic blocks, the great valleys of the Alps existed prior to their dispersion, and much observation has been directed to the sources whence particular kinds of blocks have been derived.* The magnitude of the blocks on both sides of the Alps, in connection with the distances they must have travelled from their parent rocks, has also long engaged attention. The *Pierre à Bot*, above Neuchâtel, and represented beneath (fig. 102),† affords a good example of an erratic block, perched on the side of

Fig. 102.

noticing many circumstances bearing on the subject, that "it is unnecessary to attribute to the gaseous current, considered to have been disengaged from fissures in the ground, a temperature higher than that needed to overcome the atmospheric pressure. Little would be gained by giving this current a very high temperature." . . . "The hypothesis which admits the *erratic thaw* to have been produced by vapours of moderate temperature, appears to me," he continues, "also that according to which nature would have worked with the minimum loss of heat."

* With reference to the mode of distribution of the erratic blocks in the basin of the Rhone, as also to the kinds of rocks so distributed, M. Guyot has remarked (Bulletin de la Soc. des Sciences de Neuchâtel, 1846, Archives de Genève, Sept., 1847):—

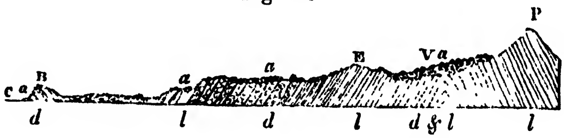
1. That a kind of rock which is abundant in one part of the basin, is rare, or absent, in another.
2. That the blocks of different kinds, commencing with the locality of their origin, form parallel series, preserved in the plain; blocks of the right side of the valley keeping to the right, of the left side to the left, while those of the centre preserve their central position.
3. That groups composed of a single kind of rock, to the exclusion of others, are here and there found in the midst of various rocks.

These views M. Guyot considers as borne out by numerous facts, and he infers that the blocks have been distributed by glaciers in the manner in which similar blocks now are by the moraines of actual Alpine glaciers. He states that similar facts are observable in the valleys of the Rheuss and Rhine.

† Taken from a view in the "Travels in the Alps of Savoy," &c., by Prof. James Forbes, 2nd edition.

the Jura, far distant from its source. This granite mass is estimated as containing about 40,000 cubic feet, and considered to have been transported 22 leagues from the crest of the Follaterres on the north of Martigny.* The blocks on the Jura have always attracted much attention from the circumstance that they must have been transported over the great valley of Switzerland, intervening between that range and the Alps. The blocks on the Chasseron are estimated as rising to the height of about 3,600 feet.† On the southern side of the Alps striking masses of erratic blocks are to be seen in the vicinity of the Lakes of Como and Lecco. They will be found high up the northern side of Monte San Primo, a mountain well separated from the high Alps by the intervening Lake of Como. The following (fig. 103) is a section of this mountain, showing the manner in which the erratic blocks rest upon it.

Fig. 103.



P, Monte San Primo; B, bluff point of Bellaggio, rising out of the Lake of Como, C; *a a a a*, blocks of granite, gneiss, &c., scattered over the surface of the limestone rocks, *l l l l*, and the dolomite *d d d*. V, the Commune di Villa, where a previously-existing depression has been nearly filled with transported blocks and minor detritus. On the north side of the Alpi di Pravolta, E, the block represented beneath, (fig. 104), is seen, one however not

Fig. 104.

* M. d'Archiac remarks ("Histoire des Progrès de la Géologie," t. ii., p. 249), that granite and gneiss generally form the blocks of the largest size. "A block of granite, on the calcareous mountain near Orsières, contains more than 100,000 cubic feet. Above Monthey, many blocks derived from the Val de Ferret, and which have thus travelled a distance not less than 11 leagues, contain from 8,000 to 50,000 and 60,000 cubic feet." . . . "The blocks of talcose granite of Steinhof, near Seeberg, one of which measures 61,000 cubic feet, has travelled about 60 leagues."

Considering the 40,000 cubic feet supposed to be contained in the *Pierre à Bot*, as French measure it would weigh about 3,000 tons.

† Necker, "Etudes Géologiques dans les Alps," vol. i. Paris, 1841.

so remarkable for size, as for showing the little attrition it could have suffered during its transport from the higher Alps to its present position.

A large amount of information has been obtained respecting the distribution of erratic blocks in Northern Europe, and the sources in Scandinavia whence they have been detached.* The area over which they have been so distributed has been shown in a map by Sir Roderick Murchison, M. de Verneuil, and Count Keyserling,† the boundary line exhibiting the southern and eastern limits of the erratic blocks extending from Prussia, to Voroneje, in Russia, and thence northwards to the Gulf of Tcheskaia, on the North Sea. It is remarked that from the German Ocean and Hamburg on the west, to the White Sea on the east, an area of 2000 miles long, varying in width from 400 to 800 miles (which may, perhaps, be roughly estimated at about 1,200,000 square miles), is more or less covered by loose detritus, amid which there are blocks of great size, the whole derived from the Scandinavian mountains.

While regarding the kind and extent of country thus more or less covered with erratic blocks, and the position which the Scandinavian mountains would occupy relatively to a large submerged area, the opinion that glaciers, icebergs (detached from them), and coast ice, may have been the chief means of dispersing the blocks and other detritus from a large isolated region, as that of Scandinavia would then be, appears far from improbable. Careful examination of the Scandinavian region itself shows that the whole land has been elevated above the present level of the adjoining seas in comparatively recent geological times, and there has been found a scoring of subjacent rocks, and dispersion of blocks outwards from it, according with this view.‡

* The observer would do well to consult the Rapport sur un Mémoire de M. Durocher, entituled "Observations sur le Phénomène Diluvien dans le Nord de l'Europe," by M. Élie de Beaumont (Comptes Rendus, tom. xiv., p. 78, 1842), wherein an excellent summary and general view of the subject, including the marking of subjacent rocks, up to the date of the observations, will be found. He should likewise consult the "Geology of Russia in Europe and the Ural Mountains," 1845, by Sir Roderick Murchison, M. de Verneuil, and Count Keyserling; chapter xx., Scandinavian Drift and Erratic Blocks in Russia; and chapter xxi., Drift and Erratic Blocks of Scandinavia, and Abrasion and Striation of Rocks; and also the "Histoire des Progrès de la Géologie de 1834 à 1845," tom. ii., prèmiére partie, Terrain Quaternaire ou Diluvien. Formation erratique du Nord de l'Europe. Paris, 1848. Notwithstanding the title, this valuable work contains information up to the date of publication. A most excellent and impartial summary of the labours relating to this subject, with original observations, will be found in this 'History.'

† "Geology of Russia in Europe and the Ural Mountains," 1845.

‡ M. Daubrée states (Comptes Rendus, vol. xvi., 1843), that the traces of transport of detritus and of friction diverge from the high regions precisely as in the Alps. This was observed up to an elevation of 3,800 feet (English). M. de Böhtlingk (Poggendorff's Annalen, 1841,) states that Scandinavian blocks have been transported

In the region occupied by these erratic blocks, ridges of them and other detrital matter have been observed to run in lines, often for considerable distances. These are commonly known as *skars*, or *ösars*.* Count Rasoumouski would appear (in 1819) to have been among the first to remark upon those in Russia and Germany, observing that they usually occurred in lines having a direction from N.E. to S.W. M. Brongniart pointed out (in 1828), that those of Sweden, though sometimes inosculating, took a general direction from north to south.† Much discussion has arisen respecting the origin of these lines of accumulation. Upon the supposition that lines of blocks may have been accumulated by glaciers, and the drift of iceberg and coast ice in particular directions, and that upon the uprise of such lines of deposits, breaker action had been brought to bear upon them for a time, we should expect very complicated evidence.

In Northern America erratic blocks are found to occupy a large area, some being strewed as far south as 40° N. latitude. Here, as in Northern Europe, the general drift of detritus appears to be from the northward to the southward, and blocks perched at various altitudes, scored and scratched surfaces of subjacent rocks, and ösars or lines of accumulation ‡ occur in the same manner. Such similar effects point to similar causes, and hence the explanations

from the coast of Kemi into the Bay of Onega, and from Russian Lapland into the Icy Sea, that is, in northerly, north-westerly, and north-easterly directions, as quoted also in the "Geology of Russia," vol. i., p. 528.

* It is worthy of remark that similar accumulations of this date, in Ireland, are known as *Escars*.

† "Annales des Sciences Naturelles," 1828. M. d'Archiac observes ("Histoire des Progrès de la Géologie," 1848, tom. ii., p. 36,) that "the form of the ösars, their disposition, and their parallelism with the furrows and scratches of erosion, naturally lead to the idea of a current which has swept the southern part of Sweden from N.N.E. to S.S.W. M. Durocher has found, with M. Sefström, that the ösars were heaped up on the southern side of the mountains which, in that direction, opposed their course. The ösars in Finland, though less marked, have a direction from N. 25° W. to S. 25° E., one which, with the preceding, represents the radii of the semicircle in which the great erratic block deposit of Central Europe occurs"

In the "Geology of Russia in Europe and the Ural Mountains" will be found the views of its authors respecting skärs or ösars. A figure is given of an iceberg aground, and the consequences of its melting stated, lines of angular and rounded blocks being strewed, as the ice dissolved, by a current acting constantly in one direction.

‡ An interesting account of two remarkable trains of angular erratic blocks in Berkshire, Massachusetts, is given by Professors Henry and William Rogers, in the "Boston Journal of Natural History," June, 1846. These two trains, one extending for 20 miles, both previously noticed by Dr. Reid and Professor Hitchcock, were traced to their sources. The blocks are generally large, the smaller being several feet in diameter. One weighs about 2,000 tons. The blocks gradually decrease in size to the S.E., those which have travelled farthest being the most worn. They are stated not to mingle with the general drift beneath them, the boulders and pebbles in which bear "the traces of a long-continued and violent rubbing." "Other long and narrow lines of huge erratic fragments are seen elsewhere in Berkshire, and abound,

offered have been of a similar general character.* A large amount of information has also been collected respecting the occurrence of these blocks, and of the polishing and scoring of subjacent rocks.† It is stated that the divergence of any blocks, such, for example, as those of the Alps, is not observed in the United States. Professor Henry Rogers points out that the scorings do not radiate from the high grounds; but that, amid the mountains of New England and in the great plains of the west, and in Pennsylvania, Vermont, and Massachusetts, they preserve a south-east direction at all their elevations; the lower parts of the great valleys being alone excepted. In the mountainous portions of the region, the heights and flanks exposed to the north and north-west are the most polished and scored. Blocks of large size have been found in New England, New York, and Pennsylvania, from 1,000 to 1,500 feet above the sea.

Erratic blocks are also found in South America. Mr. Darwin discovered them up the Santa Cruz river, Patagonia, in about 50° 10′ S. latitude, and at about 67 miles from the nearest Cordillera. Nearer the mountains (at 55 miles) they became "extraordinarily numerous." One square block of chloritic schist measured 5 yards on each side, and projected 5 feet above the ground; another, more rounded, measured 60 feet in circumference. "There were innumerable other fragments from 2 to 4 feet square."‡ The great plain on which they stood was 1,400 feet above the sea, sloping gradually to sea cliffs of about 800 feet in height. Other boulders were found upon a plain, above another, elevated 440 feet, through

we think, in nearly all the mountainous districts of New England. One such train, originating apparently in the Lennox ridge, about two miles on the south of Pittsfield, crosses the Housatonic Valley, south-easterly, as far at least as the foot of the broad chain of hills in Washington. Some very extensive ones are to be seen on the western side of the White Mountains.

* These will be found in the works and memoirs of Hitchcock, Mather, Emmons, Hall, Rogers, Hubbart, Redfield, Jackson, Christy, Ch. Martins, and other geologists.

† We are indebted to Dr. Bigsby for an early notice of the erratic blocks of North America.—(Trans. Geol. Soc., London, vol. i., second series.)

In 1833, Professor Hitchcock ("Report on the Geology of Massachusetts," art. Diluvium,) adduced abundant evidence of the northern origin of these blocks in the districts described by him. The like was also done at an early date for other portions of North America, by Messrs. Lapham, Jackson, Alger, and others. The observer will find an able summary of the facts known in 1846, on this subject in Professor Hitchcock's Address to a meeting of the Association of American Geologists in that year. Professor Henry Rogers also treated in a general manner of the American erratic blocks in his Address to the same scientific body in 1844, (American Journal of Science, vol. xlvii.) Another general summary, up to 1848, is given by the Vicomte d'Archiac, ("Histoire des Progrès de la Géologie," tom. ii., chap. 9, Terrain Quaternaire de l'Amérique du Nord).

‡ Darwin, "On the Distribution of Erratic Boulders, and on the Contemporaneous Unstratified Deposits of South America."—Geol. Trans., second series, vol. vi. p. 415.

which the same river flows, and at 800 feet above the sea. In the valley of the Santa Cruz, and at 30 or 40 miles from the Cordillera, (the highest parts in this latitude rise to about 6,400 feet,) blocks of granite, syenite, and conglomerate, not found in the more elevated plains, were detected. Mr. Darwin infers that these are not the wreck of those observed on the higher plain, but that they have been subsequently transported from the Cordillera. He had not opportunities of observing other erratic blocks in Patagonia, but refers to the great fragments of rocks noticed by Captain King on the surface of Cape Gregory, a headland, about 800 feet high, on the northern shore of the Strait of Magellan. Mr. Darwin also describes rock fragments of various dimensions and kinds in Tierra del Fuego and the Strait of Magellan, amid stratified and unstratified accumulations of a similar general character to those of this geological date in Europe.* Many of the erratic blocks are large, one at St. Sebastian's Bay, east coast of Tierra del Fuego, was 47 feet in circumference, and projected 5 feet from the sand beach. The general drift of these deposits is considered to be from the westward, the manner in which the transported fragments of rock would be carried by a current similar to that which sweeps against the present land. On the north of Cape Virgins, close outside the Strait of Magellan, the imbedded fragments are considered to have been transported 120 geographical miles or more from the west and south-west. On the northern and eastern coasts of the Island of Chiloe, extending from 43° 26′, to 41° 46′ S. latitude, Mr. Darwin detected an abundance of granite and syenite boulders, from the beach to a height of 200 feet on the land. He infers that these boulders have travelled more than 40 miles from the Cordillera on the east.†

* At Elizabeth Island, Strait of Magellan, there occurs, "fine-grained, earthy or argillaceous sandstone, in very thin, horizontal, and sometimes inclined laminæ, and often associated with curved layers of gravel. On the borders, however, of the eastward part of the Strait of Magellan, this fine-grained formation often passes into, and alternates with, great unstratified beds, either of an earthy consistence and whitish colour, or of a dark colour and of a consistence like hardened coarse-grained mud, with the particles not separated according to their size. These beds contain angular and rounded fragments of various kinds of rock, together with great boulders."—Geol. Trans., second series, vol. vi., p. 418. Variations of these accumulations are noticed as occurring in other places, and two sections of contorted and confused beds at Gregory Bay are given, and Mr. Darwin infers that this disturbance may have been produced by grounded icebergs.

† "The larger boulders were quite angular." . . . "One mass of granite at Chacao was a rectangular oblong, measuring 15 feet by 11 feet, and 9 feet high. Another, on the north shore of Lemuy islet, was pentagonal, quite angular, and 11 feet on each side; it projected about 12 feet above the sand, with one point 16 feet high: this fragment of rock almost equals the larger blocks on the Jura."—Geol. Trans., second series, vol. vi., p. 425.

CHAPTER XV.

MOLLUSC REMAINS IN SUPERFICIAL DETRITUS.—ARCTIC SHELLS FOUND IN BRITISH DEPOSITS.—EVIDENCE OF A COLDER CLIMATE IN BRITAIN.—EXTINCT SIBERIAN ELEPHANT.—CHANGES OF LAND AND SEA IN NORTHERN EUROPE.—EXTINCTION OF THE GREAT NORTHERN MAMMALS.—RANGE OF THE MAMMOTH.—FROZEN SOIL OF SIBERIA.

UPON the supposition of the submergence of a large portion of the present dry land of Northern Europe, Asia, and America, beneath seas upon which ice was formed, and into which glaciers protruded in lower latitudes than at present, we should expect to discover in the marine deposits of these regions, and of the period now upraised into the atmosphere, evidences of the marine animal life of the time having corresponded with the low temperature to which it was then exposed. This evidence is considered to have been found.

As regards the British Islands, Mr. Trimmer pointed out, in 1831, that amid the detrital accumulation referred to this date, and at a considerable height above the sea (since ascertained to be 1,392 feet), upon Moel Trefan (one of the hills on the outskirts of the chief Caernarvonshire mountains), fragments of *Buccinum*, *Venus*, *Natica*, and *Turbo* of existing species were found. He also stated that on the flanks of the Snowdonian mountains, and between them and the adjoining sea, in the Menai Straits, there were large accumulations of boulders and fragments derived from a distance, (among them chalk flints,) mingled with others of a local kind. Mr. Trimmer subsequently (1838) published a more general statement on the same subject, noticing various localities where he and others had found shells, of a similar character, in deposits referred to this date.*

* The first communication was made to the Geological Society of London (Proceedings of that Society, vol. i.); the second to the Geological Society of Dublin, in a memoir, in two parts, entitled, "On the Diluvial or Northern Drift on the Eastern

Commenting on the facts observed by Mr. Trimmer on Moel Trefan, Sir Roderick Murchison (in 1832) inferred from the previous discovery of shells of existing species in the Lancashire gravels and sands by Mr. Gilbertson, one which he was enabled to confirm from actual observation, and from finding similar accumulations over a large tract of country, that the materials of the ancient shore of Lancashire and of the estuary of the Ribble, were deposited during a long protracted period, and "were elevated and laid dry after the creation of many of the existing species of molluscs."* Numerous facts of the like kind were noticed by different observers;† but the inference as to a temperature less at that geological time than at present, as shown by the remains of molluscs, does not appear to have taken a distinct form until Mr. Smith, of Jordan Hill, published his views on the subject in 1839.‡ He discovered shells in places where their animals had lived and died, in the counties of Lanark, Renfrew, and Dumbarton, and hence inferred their entombment by depression, a half-tide deposit being converted into one in a deeper sea. From these and other researches, Mr. Smith obtained a mass of evidence which led him to conclude, from the remains of the molluscs discovered in deposits of this date in different localities, that the climate of the British Islands had then been colder than it now is, more especially as Arctic molluscs, not

---

and Western side of the Cambrian Chain, and its Connexion with a similar Deposit on the Eastern side of Ireland, at Bray, Howth, and Glenismaule."—(Journal of the Geological Society of Dublin.) Mr. Trimmer mentions that, prior to his discovery of the shells on Moel Trefan, Mr. Gilbertson had found shells of existing species in gravel and sand near Preston, Lancashire, and that Mr. Underwood had observed furrows and scratches on the surface of rocks laid bare among the Snowdonian mountains, when the great road from Bangor to Shrewsbury was in progress.

* Address, as President, to the Geological Society of London, February, 1832.—Proceedings of that Society, vol. i, p. 366.

† Among the observations of the time, and as important for the locality noticed, should be mentioned those of Sir Philip Egerton, "On a Bed of Gravel containing Marine Shells, of recent Species, at Wellington, Cheshire" (Proceedings of the Geological Society, vol. ii., p. 189, April 1835). Sir Philip notices the remains of *Turritella terebra*, *Cardium edule*, and *Murex arenaceus*, and infers that there had been an alteration of 70 feet in the level of land and sea, as regards the locality, since the deposit was formed. In 1837, Mr. Strickland ("On the Nature and Origin of the various kinds of transported Gravel occurring in England," read at the British Association in that year) took a general view of the stratified and unstratified character of these deposits, and divided them into—1. *Marine drift*, formed when the central portions of England were under the sea; and, 2. *Fluviatile drift*, when they were above its level, forming dry land, the first composed of (*a*) erratic gravel, without chalk flints; (*b*) erratic gravel, with chalk flints; and (*c*) local, or non-erratic gravel.

‡ "On the late Changes of the relative Levels of the Land and Sea in the British Islands" (Memoirs of the Wernerian Natural History Society, Edinburgh, vol. viii., p. 49, &c.) In this memoir Mr. Smith most carefully cites all those who had previously discovered facts relating to the subject, giving an account of these facts.

now found round the British coasts, were obtained from these accumulations.*

Professor Edward Forbes, in 1846, availing himself of the information then existing, and of his own researches on the same subject, pointed out that the total number of species of molluscs discovered in the deposits of the British area, and referred to this geological time, was about 124, all, with a few exceptions, now existing in the seas around the British Islands, and yet indicating by their mode of assemblage a colder state of the area than at present.† While carefully noticing the error which might arise

---

* Alluding to the researches of M. Deshayes, to whom the unknown shells discovered were transmitted, and who stated that those still found recent, but not in the British seas, occur in northern latitudes, Mr. Smith remarks that this view confirmed that which he had previously entertained from finding many of the shells common with those obtained by Sir Charles Lyell, at Uddevalla, in Sweden, and figured by him (Phil. Trans., 1835); from having been informed by the same geologist that the *Fusus Peruvianus* still inhabited the Arctic seas; and from Mr. Gray (of the British Museum) having, from a cursory examination of the shells discovered, remarked that they had all the appearance of Arctic shells. Mr. Smith adds, "In the Clyde-raised deposits, shells common to Britain and the northern parts of Europe occur in much greater abundance than they do at present. The *Pecten Islandicus*, which has probably entirely disappeared, and the *Cyprina Islandica*, which, if found recent in the Clyde, is extremely rare, are amongst the most common of the fossil species." Most valuable catalogues are appended to the memoir of Mr. Smith, consisting of lists of recent shells in the basin of the Clyde and north coast of Ireland (including land and fresh-water shells); of shells from the newer Pliocene deposits of the British Islands (also including land and fresh-water shells); and of recent species (then new) from the Firth of Clyde.

† Professor E. Forbes, "On the Connexion between the distribution of the existing Fauna and Flora of the British Isles, and the Geological Changes which have affected their Area during the Period of the Northern Drift" (Memoirs of the Geological Survey of Great Britain, vol. i., p. 367, &c.). The Professor observes that, "as a whole, this fauna is very unprolific, both as to species and individuals, when compared with the preceding molluscan fauna of the red and coralline crags, or that now inhabiting our seas and shores. This comparative deficiency depends not on an imperfect state of our knowledge of the fossils in the glacial formations—on that point we now have ample evidence—but on some difference in the climatal conditions prevailing when those beds were deposited. Such a deficiency in species and individuals of the testaceous forms of mollusca, indicates to the marine zoologist the probability of a state of climate colder than that prevailing in the same area at present. Thus the existing fauna of the Arctic seas includes a much smaller number of testaceous molluscs than those of Mid-European seas, and the number of testacea in the latter is much less than in South-European and Mediterranean regions. It is not the latitude, but the temperature which determines these differences." "That the climate," he subsequently observes, "under which the glacial animals lived, was colder, is borne out by an examination of the species themselves. We find the entire assemblage made up, 1st, of species (25) now living throughout the Celtic region in common with the northern seas, and scarcely ranging south of the British Isles; 2nd, of species (24) which range far south into the Lusitanian and Mediterranean regions, but which are most prolific in the Celtic and northern seas; 3rd, of species (13) still existing in the British seas, but confined to the northern portion of them, and most increasing in abundance of individuals as they approach towards the Arctic circle; 4th, of species (16) now known living only in European seas, north of Britain, or in the seas of Greenland and Boreal America; 5th, of species (6) not now known existing,

from neglecting the occurrence of species at different depths in the sea, he observes, that among those found in these deposits, and in situations where they must have lived and died, there are shells, such as the *Littorinæ*, the *Purpura*, the *Patella*, and the *Lacunæ*, "genera and species definitely indicating, not merely shallow water, but, in the three first instances, a coast line."*

Taking a general view of the flora of the British Islands, and of the probable sources whence its parts have been derived, Professor Edward Forbes has inferred that a portion was obtained from northern regions when the higher parts of these islands were alone above the sea, at a time corresponding with that when the marine molluscs living in the seas around them were of the character above noticed, and when the climate was colder than it now is, the evidence of the land flora thus corroborating that afforded by the remains of the marine molluscs. Under such conditions he infers that "plants of a subarctic character would flourish to the water's edge." The whole area being subsequently upraised, in the manner above noticed, the previous islands would become mountain heights, and the plants, uplifted with them, not being deprived of the climatal conditions fitted for them, continued to flourish and be distributed as we now find them.†

and unknown fossil in previous deposits. Two other species, from southern deposits in Ireland, were, one the same as one (*Turritella incrassata*) still existing in the South-European, though not in the British seas, and the other (*Tornatella pyramidata*) extinct, but found fossil in the crag." Professor E. Forbes remarks, that it is "of consequence to note the fact that the species most abundant and generally diffused in the drift are essentially northern forms, such as *Astarte elliptica*, *compressa*, and *borealis*, *Cyprina communis*, *Leda rostrata* and *minuta*, *Tellina calcarea*, *Modiola vulgaris*, *Fusus bamfius* and *scalariformis*, *Littorinæ* and *Lacunæ*, *Natica clausa* and *Buccinum undatum;* and even *Saxicava rugosa* and *Turritella terebra*, though widely distributed, are much more characteristic of North-European than of Southern seas."

* "Memoirs of the Geological Survey of Great Britain," vol. i., p. 370. The Professor adds, "a most important fact, too, is that among the species of *Littorina*, a genus, all the forms of which live only at water-mark, or between tides, is the *Littorina expansa*, one of the forms now extinct in the British, but still surviving in the Arctic Seas."

† "Memoirs of the Geological Survey," vol. i. Professor E. Forbes divides the general flora into five parts, "four of which are restricted to definite provinces, whilst the fifth, besides exclusively claiming a great part of the area, overspreads and commingles with all the others." With regard to his general view, the Professor takes, as his main position, that "the specific identity, to any extent, of the flora and fauna of one area with those of another, depends on both areas forming, or having formed, part of the same specific centre, or on their having derived their animal and vegetable population by transmission, through migration, over continuous or closely-contiguous land, aided, in the case of Alpine floras, by transportation on floating masses of ice." As respects the vegetation to which reference is made in the text, Professor E. Forbes observes, "The summits of our British Alps have always yielded to the botanist a rich harvest of plants which he could not meet with elsewhere among these islands. The species of these mountain plants are most numerous on the Scotch mountains—com-

As confirming his views respecting the effect of great cold at this period upon the marine molluscs in the seas around the British Islands, Professor E. Forbes found, while dredging, that there were depressions off the coasts in which molluscs of Arctic character still remained, as if imprisoned in cavities during the general rise of the sea-bottom, so that while their germs still found the needful conditions for their development in such depressions, when they passed beyond them, they perished.

Quitting the minor area of the British Islands, and extending our views to the great region ranging from Scandinavia eastward along Northern Asia to Behring's Straits, we should, in the higher latitudes, expect no great aid, as regards evidences of a colder climate having more prevailed at that geological time than at present, from the remains of marine molluscs entombed amid detritus,* or from the existing flora there found. Under the hypothesis of a depression of land, accompanied by increased cold, it is not difficult to conceive that the marine fauna and terrestrial flora of the region became adjusted to the conditions obtaining at the different times, the one accommodating itself to the new shores, the other creeping to the proper grounds, as the sea-bottom changed and the general temperature became lowered or elevated. The discovery, however, of large animals entire in ice, or frozen mud or sand, with their flesh and hair preserved, in high northern latitudes, and of kinds not now existing there, has been considered as affording somewhat of the evidence required.

It is now about half a century since that the body of an elephant, of a species not now living, but the remains of which are widely

paratively few on more southern ridges, such as those of Cumberland and Wales. But the species found on the latter are all, with a single exception (*Lloydia serotina*), inhabitants also of the Highlands of Scotland; whilst the Alpine plants of the Scotch mountains are all, in like manner, identical with the plants of more northern ranges, as the Scandinavian Alps, where, however, there are species associated with them which have not appeared in our country."

* The well-known mass of shells at Uddevalla, in Sweden, raised to the height of 216 feet above the level of the sea, and beneath part of which M. Alexandre Brongniart long since found *Balani* still adhering to the supporting gneiss rocks on which they grew ("Tableau des Terrains que compose l'Ecorce du Globe," p. 89), is described as composed of species still existing in the neighbouring seas. A list of these shells was given by M. Hisinger, "Esquisse d'un Tableau des Petrifactions de la Svéde," ed. 2me, Stockholm, 1831. Professor E. Forbes has pointed out that this accumulation of shells was noticed by Linnæus in 1747, and that the species discovered by him are now known as *Balanus Scoticus*, *Saxicava rugosa* or *sulcata*, *Mya arenaria*, *Littorina littorea*, *Mytilus edulis*, *Fusus scalariformis*, *Pecten Islandicus*, *Fusus antiquus*, and *Balanus sulcatus*. In 1806, the Uddevalla shells, and others of existing species, raised above the present level of the sea in Norway, were observed by Von Buch. They were also described by Sir Charles Lyell, in his account of the rise of land in Sweden, "Philosophical Transactions," 1835.

dispersed amid the later geological accumulations of the northern portions of the northern hemisphere,—its flesh so fresh that bears and wolves devoured it,—was found frozen in 70° N. latitude, near the embouchure of the Lena in Siberia.* The body of a rhinoceros also, of a species now extinct, whose hard remains are also discovered in somewhat similar positions, had been obtained in the state of a mummy by Pallas thirty years previously, in latitude 64° N., from the banks of the Wiljue, which falls into the Lena, the carcase smelling like putrid flesh, the hair still partly on the body. These discoveries long since led to speculations respecting a change of climate in Siberia, one suddenly destroying the animals mentioned by cold, so that their carcases were preserved. Professor Playfair (in 1802) would appear to have been the first to infer that the elephants and rhinoceroses of Siberia, now extinct, may have been fitted for a cold climate, though the elephants of the present day inhabit regions of a higher temperature, and that "they may have migrated with the seasons, and by that means have avoided the rigorous winters of the high latitudes."† He also considered that they might have lived farther to the south than the localities where their remains are now found, and "among the valleys between the great ranges of mountains that bound Siberia on that side." Sir Charles Lyell, in 1835, took a similar but more extended view of the subject.‡ Adverting to the mode of occurrence of the abundant remains of elephants in the deposits of Siberia,—an abundance so great that a trade in their tusks for ivory has long been established,§—to the deposits themselves in which they are discovered having been formed beneath the sea, since they contain the remains of marine shells; and to a slow upheaval of the borders of the Icy Sea, as is now taking place, he considered that a considerable change in the physical geography of the

---

* Mr. Adams, who carefully preserved what remained of this animal, relates that it was first observed as a shapeless mass by Schumakof, a Tungusian chief, and owner of the peninsula of Tamset, in 1799; that this ice-covered mass fell upon the sand in 1803, and that, in the next year, the chief cut off the tusks, the fossil ivory, if it may from its comparative freshness be so termed, found in these regions, being an article of commerce. Mr. Adams, visiting the spot two years afterwards, obtained the skeleton, still in part covered by the fleshy remains, with portions of its hair, which, together with the tusks, subsequently purchased, is now preserved in the Museum at St. Petersburg; and a description is given of it in the "Memoirs of the Imperial Academy of Sciences," vol. v., of which a translation was published, with a figure, in London, in 1819.

† Playfair's "Illustrations of the Huttonian Theory," Edinburgh, 1802.

‡ "Principles of Geology," 4th edition, 1835.

§ This fossil ivory is still imported from Russia into Liverpool, where it finds "a ready sale to comb-makers and other workers in ivory."—Owen, "History of British Fossil Mammals," p. 249.

whole region had been effected, a great increase of land northwards being the result of a long-continued and slow uprise of land and sea-bottom. He inferred a general decrease of temperature, so that the elephants and rhinoceroses, though they may have been fitted to live in colder regions than any of the kinds now existing gradually perished.

Sir Roderick Murchison and his colleagues, in the examination of the geology of Russia and the Ural Mountains, adopted similar general views, inferring that the Ural, Altai, and neighbouring regions of Siberia, were above the sea when these great mammals existed, and that they lived in herds adjacent to lakes and estuaries,* into and down which their remains were swept. It would appear, especially by the researches of M. Middendorf, that the shells found with these remains are of kinds now existing in the seas of the region, so that the molluscs of that time and the neighbouring seas have not been exposed to conditions effecting their destruction. M. Middendorf also mentions, that in 1843 the carcase of an elephant was found in the Tas, between the Obi and Yenesei, in about latitude 66° 30′ N., "with some parts of the flesh in so perfect a state, that the bulb of the eye is now preserved in the Museum of Moscow."† Sir Roderick Murchison, M. de Verneuil, and Count Keyserling also remark, when describing the range and boundaries of the erratic blocks of Russia, that the area of the districts of Perm, Viatka, and Orenburg, was probably "above the waters and inhabited by mammoths"‡ at this period.

With regard to the probable habits and food of the elephant (*Elephas primigenius*) and the rhinoceros (*R. tichorhinus*), the researches of Professor Owen have shown,§ that on physiological

* "Geology of Russia in Europe and the Ural Mountains," vol. i., p. 500.

† The discoveries of M. Middendorf, of 1843, were communicated to Sir Charles Lyell in 1846 ("Principles of Geology," 7th edition, 1847). "Another carcase, together with another individual of the same species, was met with in the same year (1843), in latitude 75° 15′ N., near the river Taimyr, with the flesh decayed. It was embedded in strata of clay and sand, with erratic blocks, at about 15 feet above the level of the sea. In the same deposit, M. Middendorf discovered the trunk of a larch tree (*Pinus larix*), the same wood as that now carried down in abundance by the Taimyr to the Arctic Sea. There were also associated fossil shells of *living northern* species, and which are moreover characteristic of the drift, or *glacial* deposits of Europe. Among these *Nucula pygmæa*, *Tellina calcarea*, *Mya truncata* and *Saxicava rugosa*, were conspicuous."—Lyell's Principles, 7th edition, p. 83.

‡ Alluding to their map, it is further observed that this probably happened, "when the erratic blocks were transported over the adjacent north-western line marked in the map, as the extreme boundary of the granitic erratics, which were, we believe stranded on or near the shelving shore of this ancient land."—Geology of Russia, vol. i., p. 522.

§ "History of British Fossil Mammals and Birds," 1846. To the previous inference that the elephant, from its warm, woolly, and hairy coat, was an animal fitted to live

grounds the *Elephas primigenius* "would have found the requisite means of subsistence at the present day, and at all seasons in the sixtieth parallel of latitude," so that by adopting, with Professor Playfair and Sir Charles Lyell, the inference that this animal migrated northwards during the warmer parts of the year, as many northern mammals now do, the mammoth, as that kind of extinct elephant has been termed, would have lived easily on the land considered to have been above water at this period. The Professor adds, "in making such excursions during the heat of that brief season (the northern summer), the mammoths would be arrested in their northern progress by a condition to which the rein-deer and musk-ox are not subject, viz., the limits of arboreal vegetation, which, however, as represented by the diminutive shrubs of Polar lands, would allow them to reach the seventieth degree of latitude." With regard to the habits and food of the two-horned rhinoceros,* found frozen in Siberia, the inferences do not appear so clear as for the mammoth. From the greater amount of hair found on the extinct and frozen rhinoceros, noticed by Pallas, than upon existing rhinoceroses, he seems to have concluded that it might have lived in the temperate regions of Asia. Professor Owen remarks that, "although the molar teeth of the *Rhinoceros tichorhinus* present a specific modification of structure, it is not such as to support the inference that it could

in a cold climate (the skin of the carcase from the Lena, and the ground on which it fell, affording many pounds weight of reddish wool and coarse long black hairs), Professor Owen showed that its teeth especially were adapted for the apparently cold climate in which its remains have been so abundantly detected. "The molar teeth of elephants possess," observes the Professor, "a highly-complicated, and a very peculiar structure, and there are no other quadrupeds that derive so great a proportion of their food from the woody fibre of the branches of trees. Many mammals browse the leaves; some small rodents gnaw the bark; the elephants alone tear down and crunch the branches, the vertical enamel-plates of their huge grinders enabling them to pound the tough vegetable tissue and fit it for deglutition. No doubt the foliage is the more tempting, as it is the most succulent part of the boughs devoured; but the relation of the complex molars to the comminution of the coarser vegetable substance is unmistakeable. Now, if we find in an extinct elephant the same peculiar principle of construction in the molar teeth, but with augmented complexity, arising from a greater number of triturating plates, and a greater proportion of the dense enamel, the inference is plain that the ligneous fibre must have entered in a larger proportion into the food of such extinct species. Forests of hardy trees and shrubs still grow upon the frozen soil of Siberia, and skirt the banks of the Lena as far north as latitude 60°. In Europe arboreal vegetation extends ten degrees nearer the pole; and the dental organization of the mammoth proves that it might have derived subsistence from the leafless branches of trees, in regions covered during a part of the year with snow."—p. 267.

* The horns of this rhinoceros have been ascertained to have been of large size. One of the horns of an individual, probably the front or nasal horn, in the Museum at Moscow, measures, according to Professor Owen, nearly three feet in length.

have better dispensed with succulent vegetable food than its existing congeners; and we must suppose, therefore, that the well-clothed individuals who might extend their wanderings northwards during a brief but hot Siberian summer, would be compelled to migrate southward to obtain their subsistence during winter."*

Considering the general evidence thus adduced as to the climate of Northern Europe at this geological time, we have to suppose a considerable depression of a large area beneath the level of the Atlantic; an increase of cold, causing glaciers to descend into the sea in Scandinavia, and even in the British Islands; a great increase, if not extension into the sea, of the glaciers of the Alps, icebergs and coast ice distributing masses and minor fragments of rocks over a considerable European area, as also the shingles of beaches, sand, and mud, accompanied by the transported remains of terrestrial and marine creatures, and a movement of land plants, with terrestrial and marine animals, in accordance with the low temperature then existing. The amount of land rising above the sea, prior to the inferred depression, is uncertain. It may have been more or less than that which we now find, though deposits of varied thickness were accumulated at this time, and now constitute a part of the dry land of Europe, and probably also a portion of the bottom of the adjoining seas.

Respecting the great mammals, the carcases of which have been so well preserved in Siberia, and admitting, with Professor Owen, their perfect fitness to have lived in a climate such as that at present found in Northern Europe and Asia, up to a high latitude, we have to consider that at the time of greater cold, their food being adjusted to it, their range, even in the summer season, would be more limited northward, not only by any coasts which might then be thrown back by the depression beneath the sea level, but also by the supposed decreased temperature. The great rivers, flowing northward, would, as Humboldt, Sir Charles Lyell, and Sir Roderick Murchison have pointed out, be then under similar conditions to the present, their embouchures exposed to lower temperatures than their courses in more temperate regions, such courses, though somewhat shorter, being still liable, as now, to be blocked up by ice at their mouths. In such a state of things there is little difficulty in inferring that the elephants and rhinoceroses lived, as they are supposed to have done, in a climate of low

* "History of British Fossil Mammals and Birds," 1846, p. 353.

temperature, and that their remains were buried in the detritus accumulated in lakes and at the embouchures of the northern rivers of the time, numerous carcases being washed out to sea and preserved amid ice, or frozen mud and sand, among deposits containing the remains of marine molluscs, such as are now living in the adjoining Arctic sea.

The cause of the extinction of the great mammals mentioned requires much consideration, and a careful observation of the facts connected with the entombment and preservation of their remains. Humboldt has remarked that the low temperature at present experienced across Poland and Russia to the Ural mountains, "is to be sought in the form of the continent being gradually less intersected, and becoming more compact and extended,—in the increasing distance from the sea,—and in the feebler influence of westerly winds. Beyond the Ural, westerly winds blowing over wide expanses of land, covered during several months with ice and snow, become cold land winds. It is to such circumstances of configuration and of atmospheric currents that the cold of Western Siberia is due."* By the immersion of the present dry land to the extent supposed,† unaccompanied by the general decrease of temperature inferred in Northern Europe, there might, no doubt, be reason to expect that such northern portions of European and Asiatic Russia as were above water would have a higher temperature than at present, but how far this would be met by such a decrease of the present temperature of Scandinavia, the British Isles, and a portion of Central Europe, that glaciers descended to the then sea level, it is more difficult to infer. Because icebergs may have floated from Scandinavia, and have become stranded on the shores of the districts of Perm, Viatka, and Orenburg, and thence along the line pointed out by Sir Roderick Murchison, M. de Verneuil, and Count Keyserling to the westward, it is not a necessary inference that the temperature of those regions, making every allowance for the influence of multitudes of icebergs at certain seasons, had been very low, more than that the temperature of Newfoundland should be that of Greenland and Baffin's Bay, whence the icebergs stranded near it are derived. Even supposing that as the land rose the temperature of Siberia became such as we now find it, it does not seem to follow, judging from the researches

* Cosmos, 7th Edit. (Sabine's Translation), vol. i., p. 323.

† The observer would do well to refer to the map given by the authors of the Geology of Russia in Europe and the Ural, for the area bounding the occurence of erratic blocks.

and reasoning of Professor Owen, that the mammoths necessarily perished from cold or the want of food.* Assuming that the great cold was unfavourable to their continuance in Siberia, that the [redacted]